Production functions for general hospitals

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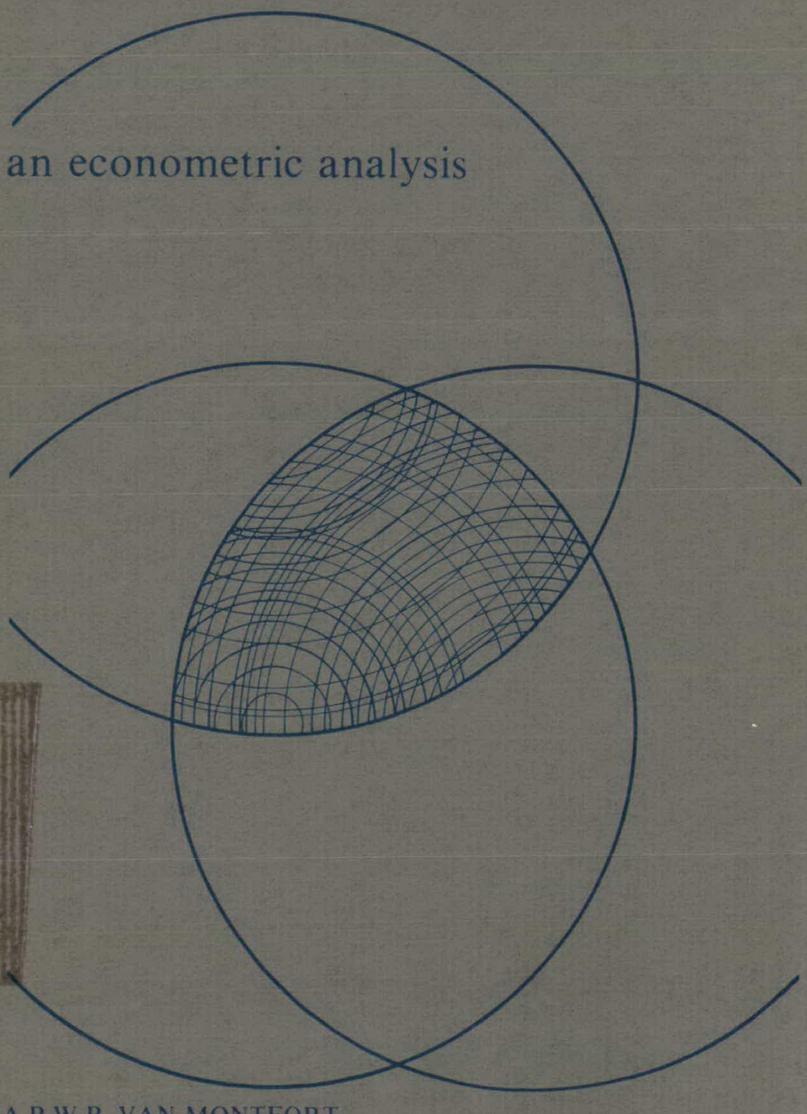
an econometric analysis



A.P.W.P. VAN MONTFORT

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PROEFSCHRIFT

TER VERKRIJGING VAN DE GRAAD VAN DOCTOR IN DE ECONOMISCHE WETENSCHAPPEN AAN DE KATHOLIEKE HOGESCHOOL TILBURG, OP GEZAG VAN DE RECTOR MAGNIFICUS, PROF. DR. J.E.A.M. VAN DIJCK, IN HET OPENBAAR TE VERDEDIGEN TEN OVERSTAAN VAN EEN DOOR HET COLLEGE VAN DECANEN AANGEWEZEN COMMISSIE IN DE AULA VAN DE HOGESCHOOL OP DONDERDAG 8 MEI 1980 TE 16.00 UUR

door

AUGUSTINUS PETRUS WILHELMUS PAULUS VAN MONTFORT

geboren te Bergeijk

1980
NATIONAAL ZIEKENHUISINSTITUUT UTRECHT

PROMOTOREN: PROF. DR. P.A. VERHEYEN
PROF. DR. L.M.J. GROOT

STELLINGEN

I

Aan het verschil tussen de werkelijke en de verwachte verpleegduur per ziekenhuis (Stichting Medische Registratie) kan een betekenis worden toegekend in het kader van een evaluatie van de benutting van de productiemiddelen per ziekenhuis. Indien de werkelijke verpleegduur lager is dan de verwachte verpleegduur impliceert dit een relatief hogere output bij de gegeven inputs.

II

Econometrische modellen (kosten- en productiefuncties) bieden bij de externe bedrijfsvergelijking de mogelijkheid de relatieve positie van een bepaald ziekenhuis -betreffende kosten en productie- te bepalen, rekening houdend met de aard van het patiëntenbestand en een aantal karakteristieken van het ziekenhuis.

III

Bij de schatting van CES-productiefuncties volgens de methode van M.S. Feldstein (Economica, 1967) dient te worden opgemerkt dat de standaardafwijkingen van de parameters conditioneel zijn op bepaalde waarden van ρ en ν.

IV

Bij een evaluatie van simulatie-experimenten kan de standaardafwijking (σ) relevanter zijn dan de standaardfout ($\sigma/\sqrt{N}$).

V

De situatie dat er grote verschillen zijn in de ziekenhuiskosten per inwoner per gebied (zie Van Montfort en Spaan, 1979), kan aanleiding zijn voor regionale budgettering, maar juist dan bergt een invoering daarvan een kostenverhogend effect in zich.

VI

De wijze waarop het "Financieel Overzicht Gezondheidszorg" door het Ministerie van Volksgezondheid en Milieuhygiëne wordt gehanteerd, duidt op het streven naar een macro-budget voor de gezondheidszorg.
Gezien de Nederlandse gezondheidszorgstructuur wekt het enige bevreemding dat dit gebeurt zonder inspraak van de betrokkenen.

VII

In de discussies omtrent kostenbeheersing en kwaliteit in de gezondheidszorg wordt vaak uitgegaan van de veronderstelling dat verhoging van de kwaliteit van de gezondheidszorg leidt tot kostenverhoging en omgekeerd dat kostenverlaging gepaard zal gaan met een kwaliteitsverlaging.

vervolg stelling VII

Voor deze stelling zijn geen overtuigende bewijzen geleverd.

VIII

Kikkert definieert enerzijds de begrippen "procedurele" en "structurele" rationaliteit, welke betrekking hebben op het beslissingsproces en anderzijds het begrip "gewone" rationaliteit waarbij uitgegaan wordt van een bepaald te bereiken doel. Gezien het specifieke karakter van de gezondheidszorgverlening ligt bij de beoordeling van projecten in de gezondheidszorg het accent niet op de "gewone" rationaliteit doch op de "procedurele" en "structurele" rationaliteit.
(W.J.M. Kikkert: Organisation of decision-making: a system-theoretical approach. Dissertatie, Technische Hogeschool, Eindhoven, 1979).

IX

Een goede relatie onderzoek - beleid vereist niet alleen een goede presentatie van de onderzoeksbevindingen maar ook de moed van de beleidsfunctionarissen -op verschillende niveau's- om de onderzoeksbevindingen in het beleid te betrekken.

X

De opleiding tot econometrist mag niet ontaarden in een opleiding tot wiskundige of statisticus. De invalshoek van de econometrie-opleiding is het economisch kenobject, bij bestudering waarvan de wiskunde en de statistiek belangrijke hulpmiddelen zijn. Voor de opleiding tot wiskundige zijn reeds betere mogelijkheden aanwezig aan de universiteiten en hogescholen.

XI

Om de toepassingsmogelijkheden van de econometrische methoden bij onderzoek naar de kostenstructuur van de academische ziekenhuizen te vergroten, verdient het aanbeveling om het aantal academische ziekenhuizen zeer aanzienlijk uit te breiden.

Stellingen behorende bij het proefschrift van A.P.W.P. van Montfort, Production functions for general hospitals.

to Henriëtte,
Martijn and Sander

CONTENTS

Acknowledgement

This thesis is intended to give a more extensive account of a part of the basic research into the cost structure of hospitals (BKZ).
The research was done by the National Hospital Institute (NZI).
Initially, the BKZ-research was, carried out by order of the Ministry of Health and Environmental Hygiene.

Professor dr. L.M.J. Groot, professor of Health Economics at the University of Maastricht, who was the initiator of the BKZ-research, was willing to generally conduct this investigation.
Also of particular importance was the fact that professor dr. P.A. Verheyen, professor of business econometrics at the Tilburg University, vouches for the econometrical supervision.
I am greatly indebted to both promotors, prof. Verheyen and prof. Groot for their many valuable advices and for their inspiring guidance.

My thanks are due to the National Hospital Institute, and in particular to dr. D. van der Meer, for the scientific capacity placed at my disposal for this research.

I also want to thank all those who contributed to the realization of this study. First and foremost I want to mention dr. J.H. van Aert who participated in the BKZ-investigation. The scientific account of the first part of this investigation may be found in his thesis (Van Aert, 1977), whereas the second part is included in this thesis.
Without this excellent collaboration I might never have come to write a number of passages of this thesis.

Of great importance, furthermore, was the close cooperation with the Mathematical Centre in Amsterdam, where dr. R.D. Gill of the Department of Mathematical Statistics, made some significant contributions to my study.

I am also very grateful to drs. P.H.C. van Drunen, J.F. Bal and P.W. van Rijnsoever, members of the Economic Research Group of the National Hospital Institute.

Of great value were the discussions I had with dr. J.M.G. Frijns, dr. J.E.J. Plasmans and dr. J.P.C. Kleijnen of the Tilburg University.

The intensive meetings with the BKZ-discussion group, were highly encouraging. Participants in these discussions were:

Prof.dr. L.M.J. Groot, prof. of Health Economics,Maastricht, chairman; dr. O. Fokkens, director of the Medical Registration Foundation, Utrecht; H. van Giffen, lung specialist, Utrecht; dr. L.P. de Jong, general manager of the Sint Antonius Hospital Utrecht (until 1-4-1979); J.W. van der Kouwe, medical director of the Academic Hospital Groningen; dr. P.C.J. van Loon, counsellor of the Long Term Planning, Department of Health and Environmental Hygiene, Leidschendam; dr. J.Th. Planten, eye specialist, Leeuwarden; dr. F.F.H. Rutten, Department of Health and Environmental Hygiene, Leidschendam; drs. T. Stolk, director Diaconessen Hospital Breda (since September 1979); drs. J.B.M. Verhey, chairman Board of the Academic Hospital Maastricht; prof.dr. P.A. Verheyen, professor of business econometrics, Tilburg.

My grateful acknowledgements are due to the National Hospital Institute for the facilities placed at my disposal and for financing the translation of my thesis.
I want to express my sincere appreciation to mrs. W. Bakker-Otten and to ms. J. Schreuder for their careful typing-work; to mr. A. van Hoornaar who took care of drawings and lay-out; and to mr. P. Thomas who attended to the printing-work.

Last bu not least I would like to thank my parents and my wife.

Nieuwegein, March 1980 A.P.W.P. van Montfort

Introduction

This thesis is the scientific study for a portion of the Basic investigation into the Cost Structures of Hospitals (in Dutch abbreviation: BKZ).
This investigation, initially commissioned by the Ministry of Health and Environmental Hygiene in the Netherlands, is being conducted under the auspices of the National Hospital Institute (in Dutch abbreviation: NZI). It explores the possibility of an econometric approach in attempting to obtain an understanding of the cost and production structures of general hospitals in the Netherlands. One reason for conducting this study is the desirability of a better understanding of the reasons for the sharp cost increases in the hospital sector. Which factors determine the cost increase? How are the productionfactors being used?
The first part of this study centers around an analysis of the cost structure in general hospitals in 1971. Several reports have been published on this subject (Groot, 1971; NZI, 1974 and 1975; Van Aert and Van Montfort, 1976; Van Aert et al., 1976a, 1976b, 1976c; Van Aert, 1977).
The central hypothesis in the construction of cost functions was that such factors as hospital function, capacity, capacity utilization and other hospital characteristics are the most important grounds for the explanation of the cost differences between hospitals. In the course of this study it became apparent that this was indeed the case. A large part of the cost differences can be explained with the aid of the constructed cost models. The parameter estimates are in general in accordance with the proposed hypotheses.

The object of this thesis is to explore the possibility of obtaining a better understanding of the production structure and functioning of general hospitals by means of production functions. The nature of this study is methodological and exploratory. Using data from a large number of hospitals in a certain year, the applicability of the production function theory is analysed. The production function is a (technical) relationship between output and inputs (Cramer, 1971 and Walters, 1973). With the aid of production functions it is possible to obtain a better understanding of the allocation of the production factors.
The central hypothesis is that one can speak of systematic relationships between, on the one hand, the differences in output, and, on the other hand, the differences in inputs. It is assumed that there are systematic elements present in the allocation and use of the inputs.
In this study, output is not defined in terms of the "outcome" of medical services, but, by necessity, in terms of the treated patients or the production of services. Inputs are understood to be the size of the staff, medical specialists, number of beds, facilities and drugs.

When one is able to quantify the production structure of hospitals, one obtains an understanding of a number of economic characteristics such as the outputelasticities, substitution possibilities between inputs, and scale effects. This has significance both in the area of planning as well as in exploitation evaluation. In the area of planning more insight into the impact of the inputs on output and into different input combinations is desirable.
Our production function indicates which alternative input combinations have been realized in practice.

In the area of operations evaluation insight into the allocation of inputs is given by the production function. Given the relationship between the cost function and the production function, this thesis, as was the thesis of Van Aert, is based on the year 1971. We intend eventually to analyse the cost and production functions taken over a number of recent years. This can be realized upon completion of the data compilation which is being carried out within the framework of this Basic Investigation (NZI, 1974, 1975 and Van Montfort et al. 1979).

Concluding this introduction is an overview of the contents of the following chapters. Chapter I presents an elaborate introduction and summary of this investigation. This chapter can be read without extensive knowledge of econometric methods and techniques. It begins with a description of the propounded problem, the hypothesis, and the production structure of the Dutch hospital sector. Thereafter follows a brief outline of the production function theory for the uninitiated, whereby particular attention is paid to those aspects relevant to this study. Specific attention is paid to the relationship between production functions and cost functions. After a theoretical part, there follows a description of several model estimates, while the interpretation and significance of the production function is examined in depth. Finally, several possibilities for the implementation of production functions and cost functions are indicated.
We draw the conclusion that the production function theory offers good possibilities for a better understanding of the production structure of general hospitals.
In the chapters following chapter I, a more detailed investigation per section is given.

Chapter II contains a discussion of the application of the production function to the hospital sector in other countries. It may be concluded that the production function theory is applied in a number of different ways and that consequently differing results are obtained. Chapter IV compares some results with the results of our study.
Chapter III is an extensive study of the theoretical framework for the application of the production function to hospitals in the Netherlands. The outputs and inputs are defined and the allocation procedure is described.

Chapter IV contains a number of different production function specification estimates. In chapter V some evaluation indices for the behaviour of hospitals are discussed. These indices are based on the estimated cost and production functions, and contribute to a more differentiated external comparison of hospitals (interhospital comparison).

Chapter I: Goals, methodology and results

This chapter summarizes in broad outlines the contents of this thesis. It deals with a number of aspects which will be investigated in further detail in later chapters.

I.1. Proposition

The rising costs of hospital operation have in recent years gained more and more public attention; costs in general hospitals have since 1968 risen with average yearly increments of 18,3%. This increase corresponds for approximately 60% to the increases of the prices of production factors (eg higher salaries, higher price of drugs), and for 40% to the increase in volume (eg more staff, more drugs) [1]. Although the absolute increase in costs of the hospital sector has diminished in recent years, an increasingly large portion of the gross national product is involved. Within the framework of macro-economic considerations, this development has led the government to desire a greater degree of cost control, and a greater control over the developments in the hospital sector in general (Ministerie van Volksgezondheid, 1974; Tweede Kamer (Parliament) 13951, 15081 and 15540). Policy adjustments in the hospital sector are affecting a large number of different aspects, such as the reduction of the number of beds, function control, wage controls etc. Furthermore, there exist proposals for experiments in budget financing instead of the present tariff system, with the aim of more accurately balancing costs against revenues (Groot, 1979 and Verheyen, 1979). Insight into cost and production structures in the hospital sector offers one the opportunity of scrutinize the consequences of certain policy proposals.
In the same vein of thought as Van Aert (1977), who examines extensively the applicability of cost functions to the hospital sector, this thesis examines the applicability for the hospital sector of production functions. As in the case of cost functions, the hospital is taken as an economic unit rather than as a number of separate processes which take place in hospitals or certain departments therof.
Within a hospital we can define a number of outputs and inputs or production factors. The question is whether with the aid of production functions the relations in the differences in outputs and inputs between hospitals can be quantified. It is assumed that there are systematic relationships between, on the one hand, hospital outputs in terms of patient treatment, training and research, and on the other hand the inputs in terms of the number of beds, the size of the staff, the number of specialists, the available facilities, drugs etc. This implies that in the behaviour of hospitals we assume the presence of a number of systematic elements in the allocation and use of the inputs. Before segmenting this proposition into a number of concrete hypotheses, we will describe the allocation process in the hospital sector. Based on this description, a number of hypotheses can be formulated and tested on the data compiled within the framework of the BKZ (Van Montfort et al., 1979).

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1) See for more details Van Montfort and Spaan, 1978 and Van Montfort et al., 1979.

This database contains a large amount of information per hospital taken over a number of years. This information comes from different sources and involves a large number of data catagories.

I.2. Description of the Production Structure of General Hospitals

The allocation process and the utilization of allocated inputs in the hospital sector is a complicated process. There are internal, hospital-bound, factors and external factors, such as regional contacts, government influence and other central policy-making agencies which all play their part herein. Furthermore, there exists a delay factor in adaptability of a hospital. It is not possible to effect major changes in a hospital on a short term basis (such as the number of beds, staff-size, buildings). Decisions made in the past determine to some degree the policy options available at this moment. We shall briefly describe several aspects of this process, while chapter III examines this subject more extensively.
In a hospital, patients are examined and treated either inpatient or outpatient with the aim of improving, or preventing the deterioration of the health of the patient (WHO, 1969; Berki, 1972). To this end, a hospital needs production factors such as buildings, installations, beds, medical specialists, staff, drugs etc.
The medical specialist carries the responsibility for the examination and treatment of the patient. The role of the hospital cannot then be seen as one of only creating a certain set of conditions, but carries in our opinion also a responsibility for the treatment of the patient.
The Ministry of Health and Environmental Hygiene, the Council for Hospital Facilities (in Dutch abbreviation: CVZ) and the Central Organization for Hospital Tariffs (in Dutch abbreviation: COZ) have legal competence with respect to the determination of the allocation of inputs as well as the quality control of hospital services. The Council for Hospital Facilities (CVZ), formerly the Hospital Commission, exists since 1972 as the legal advisory council for the Ministry with respect to the planning and building of intramural health care facilities (investment). In this capacity the council has proposed a number of guide lines and norms (College voor Ziekenhuisvoorzieningen, 1973) which have been enforces by the Ministry (Ministerie van Volksgezondheid en Milieuhygiëne, 1979b). With regards to hospitals we can mention the $4^{0}/_{00}$ norm for hospital beds, a minimum and a maximum size for hospitals, and function controls. This latter regulation dates from 1976 and concerns limitations in attracting new specialisms and the related expansion of facilities. It should be noted that the intended reduction in the number of hospital beds and the retardation of function development has up til now been realized only marginally (see Van Montfort et al., 1979a).

The training of medical specialists is controlled by the Central Board for Acknowledgement and Registration of Medical Specialists[1)] (Centraal College, 1979; de Vink, 1972). This board composes their list of requirements with reference to the specialist training. These requirements can roughly be divided into the following 3 categories: the training programme, the teacher and the training institute (the hospital).
It sets the standards which must be met (see also Van Aert en Van Montfort, 1978a en 1978 b). The government has indirect influence over the number of new interns through the numerus fixus for medical schools. It must be noted that this numerus fixus was not intended for this purpose but is strongly related to the limited capacity of medical schools.
The COZ has developed a set of norms and guide-lines for the exploitation of hospitals (Centraal Orgaan Ziekenhuistarieven, 1978). Guide-lines have been developed for the regulation of the size of the staff per department (eg nursing dept, treatment dept, management and administration, civil services and technical services). These guide-lines are related to production levels (eg patient days, and the number of treatments). The norms of the COZ are not then related to the production volume. This is however the basis for the application of the guide-lines and norms.
With respect to depreciation the basis is the historical cost price of assets. A linear depreciation scheme was established for the various investment catagories. Interests, which are calculated through into the costs of a hospital, are equal to the interests actually paid for the debts incurred for the payment of investments. The level of investment is for the COZ a constant. As previously stated, the CZV has set guidelines for the investment in buildings, installations etc. Investments in medical inventories are largely excluded from these.
The budget for a hospital in a particular year is based on the expectations regarding the development of production volume which in turn forms the basis for the allocation of inputs. Considering that it is often difficult on a short term basis to adjust the inputs to deviations from the expected production level, the real input levels will, to a large degree, be correlated to the expected production volume, rather than to the real production volume.
The revenues of hospitals are based, on the one hand, on the pre-calculated patientday-tariff (possible also on some treatment tariffs), and, on the other hand, on the realised production. The development in revenues will be proportional to the changes in the production volume. Because of the low marginal costs, costs as a whole will vary much less proportionally to changes in production volume. This implies that when the production levels deviate from the expectations, exploitation surplusses or deficits may occur.

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1) The training of pharmacists, oral specialists and surgeons, dental maxiliary orthopedics, clinical pharmacists (not MDs) is not regulated by the Central Council

As already noted, the norms and guidelines set by the COZ do not concern the production volume. The maximum production volume will, on a short term basis, be dependent on the inputs within the hospital, such as the number of beds, the available outpatient rooms, the equipment, the staff and the number of specialists. These are rather difficult to change on a short term basis. The marginal costs of an extra patient-day or treatment are in general quite low. This leads us to the question, which are the factors that do determine the use of hospital facilities. The demand for hospital services will depend on the development of such factors as the aging of the population, morbidity developments (heart disease, traffic accidents). The demand for hospital facilities will also be determined by the supply of services. From various studies, conducted both in the Netherlands and elsewhere, one can draw the conclusion that the "availability effect" plays a very important role. A greater supply leads in general to a greater realised demand. Besides the availability effect, the decisions taken within the context of the given facilities also play a role.
The variations in use concerns admission and discharge of patients, the number of treatments and the outpatient activities. Out of information from Medical Registration Foundation (in Dutch abbreviation: SMR) (SMR, 1976) and LISZ (National Informationsystem for sick fund patients; in Dutch abbreviation: LISZ) great differences emerge in admission coefficients per diagnosis, per region, as well as in the length of stay per diagnosis. In Van Montfort and Spaan (1979b) we see great differences in hospital costs per inhabitant per region.
It might be deduced from this that the output in a certain year is to a large extent endogenous with respect to the input. Of course this is not the case for all patients. The number of traffic accident victims will not be related in any way to the number of beds in a certain region. However, within a certain year it will not be possible to adjust the inputs to a sudden increase or decrease in traffic accidents victims. This does not mean that over a longer period of time the allocation of inputs will not be influenced by developments in specific demand determinants (see also Belleman, 1977). This implies that exogenous changes in demand on a short term basis, will not lead to a corresponding adjustment of inputs. This lead to variations in the utilisation of the inputs. It is noted, however, that differences in occupancy rate of beds, as well as that of the treatment departments are dependent on more than one factor.

The production process described above can be studied at different aggreation levels. It is possible to study at the patient-level how many inputs are directed towards examination and treatment (see for example Groot, 1977; Fetter c.s., 1977; Verheyen, 1975). One can also study the relationship between the patients treated and the production factors for the hospital as a whole. An advantage of the approach at the patient-level is that insight is obtained into the utilization of production factors per type of illness. A disadvantage is that the decisions taken are not placed in the light of the total of available production factors in the hospital.

In our study the hospital as a whole will be the subject of research.

To conclude the description of the production structure we will further examine the goals of hospitals and the subsequently related definition of output.
In micro-economic theory the goal of an enterprise is stated as being either profit maximization or cost minimization. Considering the policy of the government and other central agencies profit maximization as a goal for hospitals is explicitly eliminated.
A number of authors, for a number of reasons, eliminate cost minimazation as a goal as well (see Van Aert, 1977). The goals of a hospital alone as conditioning for the treatment of patients appear to us as being too limited. Regarding this point, Van Nieuwenhuizen (1971), states that the specialist is becoming increasingly subordinate to the management and board of the hospitals. The board is gaining an increasingly strong influence on taking of final decisions within the hospital as well as on the external relations of the hospital. Additionally, the development of other disciplines and services (e.q. bio-chemists, medical physicists, but also psychologists and sociologists) is playing an increasingly important role in this process (for this, see Van Nieuwenhuizen 1974, 1978). Groot (1978) comments: "The care of patients in this context is seen as the result of the combined efforts of specialists and hospitals, a vision in which the hospital board has the final responsibility for the policy and the way on which the hospital in total is fulfilling their task". Rogiers (1979) on the basis of an analysis of the developments in the hospital sector, concludes that a split between hospital and medicine is not a tenable one.
From this one can drawn the conclusion that the hospital too has a responsibility for, and a direct task in medical care. To make these goals operational in economic terms is, as the literature indicates (chapter II) very difficult. We have therefore chosen to use a more direct approach for this study. On the basis of a number of hypothesis we hope through empirical analyses to obtain new insight into the behaviour of hospitals. A hospital is trying to satisfy a demand for (para)medical and nursing services (patient care). In other words, the activities (production) within a hospital must in principle be evaluated in the light of their contribution to health of the patient ("out-come"). For a complete study of this, it will not be sufficient to limit ourselves to the treatment of the patient in a hospital. Rather, the activities in extramural health care (eg family docters), nursing homes, psychiatric institutions etc., must also be taken into account. Such an evaluation would to a large extent be of a medical nature, but in the light of scarcity and alternative allocation possibilities of the available factors of production, the economic discipline ought to play a role as well.
Up till now, such studies have only been suggested. In this study we will then not be concerned with the "effect" of the production on the health status of the patient but we will concentrate on the production itself.

The number of patients treated, and the production in terms of patient-days, treatments, outpatient visits etc., can be mentioned in this respect.
These are also the basic concerns with such policy-making agencies such as the Ministry, the CVZ, the COZ.
Aside from patient care, the hospital also has training functions. This concern training of nurses, paramedical training, interns, and specialist training. Considering that inputs are allocated to these activities, they will have to be included in this study. Research, in particular medical research, is also conducted in hospitals. The type of research, or the amount of research that is being conducted is not known and will therefore not be taken into consideration[1].
The output of a hospital also contains a quality aspect. The methodology of quality measurement in health care is not very highly developed (Stolte, 1977). Sometimes a difference will be made between the evaluation of treatment ("outcome" approach), and the evaluation of the production process ("process" approach). Both approaches have hardly been made operational till now. Regarding the quality measurement of nursing analogous comments have been made (Van Maanen, 1978; Hagyvary, 1976a and b). In our study the quality aspect of health care services is not explicity included. In as much as quality aspects are connected to variables which are included (such as facilities, length of stay) their quality is implicity included.

I.3. Production function; some theoretical comments.[2] What is a production function?

The object of this study is to evaluate the applicability of the production function theory for the (general) hospital sector. In this section we will discuss the production function theory in general. This concerns only a general introduction for there who are less familiar with the production function theory[3].

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1) The report of the study group Van Leeuwen (Ministerie Volksgezondheid en Milieuhygiëne, 1974b) mentions, apart from the three elements we have mentioned, also the cooperation with other institutions as an element of the function of a hospital. In our vision this is not a specific policy option, but a way in which one can realize the three mentioned hospitalfunctions.

2) In chapter II a number of these aspects are worked out and a number of studies regarding application in the hospital sector are treated.

3) For an extensive discussion on production function theory the reader is refered to Cramer (1971), Johansen (1974), Samuelson (1948 and 1976), Wallis (1973) en Walters (1963).

A production function represents the technical relationship between input and output. Production is a physical process, which transforms inputs into outputs. It is possible to have a number of technical alternatives for this transformation process, which are represented by the function. The production function offers insight into the technical substitution possibilities, the marginal productivities of various input factors and the effects of scale. This allows one to determine which combinations of inputs can produce a certain output (substitution).
It is possible to study a production process at various aggregation levels. For instance one can formulate a production function for enterprises in a certain sector. One can also analyse the production process within a certain enterprise.

Engineering versus statistical estimation methods

A quantification of the production function may be obtained by various methods. Walters (1963) differentiates between the statistical method and the engineering method. In the statistical method the production function is estimated form a series of observations of inputs and output . This series can be a cross-section (a number of enterprises in a certain year), and/or a time series (an enterprise taken over a number of years). The engineering method focusses the attention much more on a detailed description of micro production relationships in physical terms (= process functions). The emphasis lies on technical production data. Consequently, one can, starting with certain prices of the inputs, the conditions with respect to the availability of factors of production, and the desired output, derive the implied cost functions.
As advantages for the engineering method Walters mentions that the range of technical possibilities is known, that it is relatively simple to absorb technical improvements into the analysis, and that one is not dependent on variations in actual observations such as in cross-section or time series analysis. A disadvantage in many instances is that there will be interaction effects between the different process functions.
The two methods can lead to different production functions for the entire organization. The process function resulting from the engineering method will implicitly contain managerial capacities. These are contained in the technical data. In the production function based on the statistical method, managerial capacities -at least to the extent that they differ between organizations- will be absorbed by the residual in the regression model.
The process function will only be able to describe technical processes. This means, that such a function can not include all the activities. The production function based on the statistical method can do this, since this is based on the organization as a whole.

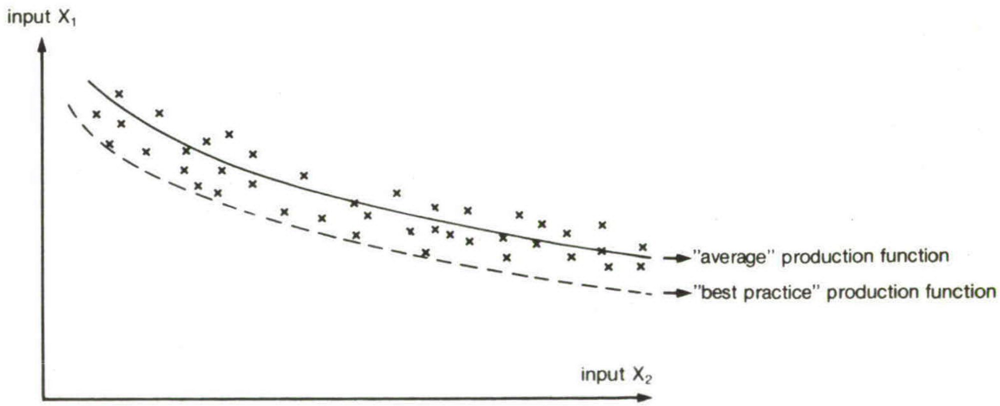
Besides Nerlove (1965) mentions that the engineering method will lead to too much detailed information. Farell (1967) too is of the opinion that the engineering method will not lead to a satisfactory production function for the entire organization. In the formulation of production functions in the hospital sector one will have to choose between the different methods. The choice depends on the goal of the study.
In our study the basis is the hospital as a whole. With reference to the above we conclude that the statistical method is more appropriate than the engineering method. For the latter, such studies as one into the activities for the individual patient might be more appropriate. In other words, what decisions does a specialist take in the examination and treatment of a specific patient. Such a micro-study offers insight into the treatment profile for a certain type of patient (Fetter et al., 1977, and Van Amstel et al., 1979). A disadvantage is, however, that one loses the setting of the hospital as a whole, withing which the specialist functions (Van Aert and Van Montfort, 1980). As suggested by Groot (1977) it would be best to strive for a synthesis between the two approaches. It will then be possible to place the decisions of the specialist at the micro-level within the framework of the hospital where he works.

The characteristics of the production function

In economic theory it is often assumed that an organization strives towards profit maximization or cost minimization. Based on certain market assuption (full competition on input and output markets), such goals imply that production is fixed at the point at which the marginal productivities of the inputs equal the inputprices. The production function which can be derived from this -based on a cross-section, or time series analysis- represents the technically most efficient production possibilities. In such an approach one assumes explicitly a certain optimality behaviour of the enterprises. If a certain concept is possibly realistic for other sectors, one can be more doubtful with respect to the hospital sector.
Berki (1972) provides a number of arguments why certain hospitals do not produce according to the most efficient production techniques. On a short term basis, certain inputs will not have a variable, but a fixed nature. It is difficult on a short term basis to adjust the number of beds or to reduce the staff. This implies that it is not possible to effectuate the best technical production technique at a certain moment in a certain hospital. A second reason can be that the substitution possibilities between inputs is not only determined by technical factors but also by institutional, professional (status-bound) and social factors as well. It is also possible that the "technical" information necessary is not know by everybody.

Summarising, it can be stated that at a certain moment within the hospital sector there exists a set of input configurations for the production of a certain output with a differing degree of efficiency[1]. If one constructs a production function on the basis of a cross-section analysis, then the parameters are averages for the whole production sector (Hoch, 1962); such a production function does not represent the line of the technically most efficient production possibilities, and this is not a "least cost" production function.
These are the parameters as they emege from the estimation procedure (empirical parameters). It is assumed that these parameters are valid for every hospital. Variations are seen as differences in productivity. In other words, differences in productivity are regarded as neutral with respect to the form of the production function. Evans (1971) states that such an approach approximates a "behavioral" rather than a technical function. Feldstein (1967b) calls this production function which is based on cross-section analysis, an "average production function". Such a production function indicates how at a certain moment the inputs, taken on the average, have been allocated, and subsequently how the inputs have been utilized in terms of outputs. It is possible on the basis of empirical observations to obtain somewhat more insight into a more efficient production function.

Grafic 1: "Average" and "best practice" production function



1) Johansen (1972) differentiates between an ex-ante and an ex-post production function. The ex-ante production function describes the technical production possibilities from which one can choose at a certain moment when installing a production unit. It is difficult to estimate this function from empirical observations. Sometimes, under very strict conditions, it is possible to do this on the basis of a cross section study. The ex-post function is concerned with the relationship between the current-inputs and outputs, given the fixed inputs (capital, installations) present at a certain moment. The difference between ex-post and ex-ante is particularly significant at the micro-level.

The "average" production function has been estimated with the aid of the least squares method (Graphic 1). One can also fit an envelope curve, the "best practice production function". This "best practice production function" can be estimated in various ways (see Aigner and Chu, 1968). Kurz and Manne (1963) first estimate the "average production function". Then the enterprises above this function are eliminated. These enterprises are relatively less efficient. Then, on the basis of the remaining entreprises, a new function is estimated. This process can be repeated and an approximation of the "best practice" production function is obtained. Because of the elimination procedure, however, this function is based on quite a small number of observations.
In this study we will estimate "average" production functions, based on a cross-section for 1971 and thereafter we estimate a more efficient production function. Such a production function will be primairly descriptive in nature (Johansen, 1972).

The relationship "production function" - "cost function"

In the preceding discussion, two direct methods for quantifying the production function have been mentionned (engineering method, statistical method). In our study we have chosen for the direct estimation of an "average" production function from information regarding the output and inputs of a number of hospitals in a certain year, by means of the statistical method. The production function may also be determined by an indirect method. According to the duality theory (Shephard, 1963; Smith, 1978[1])), the production function can be derived form the cost function. By multiplying the input quantities with their prices, we obtain costs. Thus the production characteristics may be derived from the cost function.
Assuming a certain model specification, object function (profit maximization or cost minimization), full competition and given inputprices, the relationship between production and cost functions can be obtained quite simply mathematically (Walters, 1963; Nerlove, 1965; Wallis, 1973). Walters (1963) states that if any one of the above assumptions is invalid, it becomes very complicated to derive the duality relationship between the cost and production functions.

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1) Smith (1978) notes that often the choice is made for the derivation of a cost function to obtain the dual production function, because the data necessary for a direct estimate is usually not available. Usually the available information regarding costs and input prices is much better than the information regarding input levels. In our case, however, as we shall see, the necessary information regarding input levels is available.

If the inputs are not exogenous with respect to the outputs, this means that the residual is dependent on the input levels (simultaneous equation bias) . One will then have to estimate a cost function and derivate the production function from this. When the realized inputs are exogenous with respect to the realized output, one can estimate the production function directly.
From the description of the production structure of the hospital in the previous paragraph, it can be concluded that the inputs are "predetermined" with respect to the realized output. In other words, the allocation of inputs occurs as a function of the expected output rather than in function of the realized output, or as a given by decisions taken in the past, and only variable on a long term basis. In this situation in the direct estimation of the production function we are not bothered by a simultaneous equation bias (Hoch, 1958, 1962). Drugs are an exception in this respect. With respect to this input one may ask whether it is not dependent on the real input level, since the adaptibility of drugs is much greater than that of other inputs. Still out of some estimated models in which this specific relationship with respect to drugs is taken into account, it may be concluded that there is no, or hardly any, question of simultaneous equation bias (see appendix III.1).
When a production function for hospitals is estimated directly the question arises how the dual cost function can be extrapolated from this. In the BKZ, cost functions have been estimated for general hospitals (Van Aert, 1977). These cost functions are intended to indicate a number of systematic factors for the differences in costs for a certain year, such as hospital function, capacity, utilisation of capacity, training programme, building year, ownership and to quantify their influence on costs. In this cost function, the output prices do not play a role. In the dual cost function however, the input prices do, according to neo-classical economic theory, play a central role. The marginal productivities of the inputs equal the input prices. We are of the opinion that the influence of input prices for the allocation in hospitals is much less relevant than is assumed by the duality theory. The rise in input prices (staff, raw materials, etc.) is directly compensated through the annual calculations scheme of the COZ, in the hospital tariffs. Salaries of employees in the hospitals are based on national scales. There is some salary differentiation on a regional scale for administrative and maintenance personeel. The capital costs in the hospital sector are calculated in a specific manner. As already noted, depreciation is determined on the basis of the historical cost price of investments, via a linear depreciation scheme. The interest paid on external capital acquired to finance investments may be calculated through the costs. It may be deducted from this that the prices of the inputs do not play the role in the allocation process that the neo-classical theory assumes they do. From cost functions for the period 1968 through 1973 it may be concluded that inflationary developments have a little or no influence on the cost structure. This can be explained by the procedures with respect to input prices described above.

Besides the specific nature of the prices of inputs, some factors have another meaning in the production function than that they have in the cost function.
The number of specialists is an essential input factor in the production function, while specialists' fees are generally not included in the hospital costs. There are some categories of costs that play an essential role in the production function, but that are included in hospital costs. The costs of the number of beds and facilities (depreciation and interest), because of the depreciation policies of the COZ, are strongly dependent on the year of purchase. Their significance for the production, however, does not depend on their age.
The relationship between cost and production functions depends also on the goals of the organization and the market-forms confronting it. The market-form for hospital services is characterized by De Jong (1967) as being an oligopoly, with, however, elimination of the price politics between suppliers.

The financial structure of the hospitals is a central point in this. The price mechanism, as regulator between supply and demand in hospital services, has been put out of action by the system of social insurances. The suppliers play an important role in the specification of demand.
It can be concluded that the duality relationship between cost and production functions for the hospital sector is not as strict as is assumed by neoclassical economic theory. In further studies with respect to the relationship between cost and production function, it is important to take into account the dynamic aspects of the allocation behaviour of the hospitals.

I.4. Problems in estimating production functions

In constructing a production function, one is faced with three problems:
a) definition and measurement of the output
b) definition and measurement of the inputs
c) model specification.
We will subsequently indicate how these problems have been treated in our study. Chapter III discusses this in detail.

I.4.1. Definition and measurement of the output

It is difficult if not impossible -up untill now- to measure the output in terms of the effect of the hospital services on the health status of the patient ("outcome"). There is -at the moment- no measuring-instrument for this. This would mean including not only hospital services, but also other echelons of the health services system.
In our study the output of the hospital is measured in terms of the number of patients treated (inpatient and out-patient) and in terms of the training functions. In the examination and treatment of patients there is a "production" of patient days, treatments, outpatient visits, etc.
In our investigation we do not evaluate the production in terms of medical effectiveness.

This does not mean, however, that the level of production by the laboratory is only a medical question. Considering the scarcity of inputs, as well as the possible alternatives in the process of health care, this question also has an economic dimension.
We will approach the output via two lines:
a) in terms of patient care and training programmes (weighted admissions/weighted patient-days);
b) in terms of patient-days, operations, laboratory tests, X-ray, examinations, outpatient visits etc. (intermediary production).
The question is how to quantify these output units. We will consider the two approaches.

Ad a.

The relevant elements identifiable with patient care and training programmes will have to be brought under a common denominator. This can be done in a number of ways.
In Chapter IV a large number of alternatives are tested. Finally two possibilities are chosen by which patient care and training programmes are brought into one unit, by means of weighing, i.e. weighted admissions and weighted patient days, respectively. Through a weighing mechanism, the heterogeneity in the number of admissions and patient-days (different type of admissions and patient-days) respectively, the outpatient clinic and the training programme are all explicity taken into account in the output unit. The parameters of the concerned variables from the cost functions are taken as the weighing coefficients. These variables are for patient care: the degree of despecialization, the percentage of ENT-patients and the outpatient variable and for the training programme: the specialist training[1].
Feldstein (1967b) states that the coefficients indicate the relative costs that society is willing to pay for hospital services through the social security system. In this sense, the meaning of the coefficients are parallel to the price of goods and services in the "market". This weighing system may raise the question whether or not a tautology is thereby introduced, or in other words, whether one does not explain costs (output measurement) from costs (inputs). One should note however, that this study is concerned with explaining differences in inputs. The cost coefficients are national parameters and thereby equal for all hospitals. This implies that a certain hospital will not have a higher calculated output because it has higher costs. This will be the case, however, if the hospital in question has a more complicated patient-load or a more extensive training programme in comparison with other hospitals. The calculated output will then not equal the total costs of a hospital. It will indicate the position, concerning the output, of a hospital in comparison with other hospitals. The definition of the output can lead to inaccuracies. On the basis of the definition of the weighted admissions a hospital may obtain a higher output by, for example, treating certain catagories of patients in two periods rather than in one uninterrupted periode more as in other hospitals. An inaccuracy in this output definition may also be related to a false relationship between the weighted coefficients. In numerous tests with the cost functions no such indication were obtained (Van Aert, 1977).

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1) For definitions see Appendix I.1.

Ad b.

Intermediary production is defined as the sum of all patient days[1] and treatments (such as operations, laboratory tests, outpatient visits etc.). There is, however, a large diversity in types of treatments. On the basis of the tariffs, these treatments are brought under one denominator. The tariffs are uniform for all hospitals. According to the COZ the treatment tariffs are a representation of the variable costs and an additional charge for the direct fixed costs of a certain treatment. The outpatient clinic is included through the revenues from leasing out outpatient rooms. For the patient-day tariff, the national average is taken as a basis. A complication here, is that in some hospitals not all treatments are declared separately. The "all-in" element is therefore eliminated from the patient day tariff. This represents the revenues from the "all-in" treatments had they been declared separately.

Both output definitions have a twofold nature. The weighted admissions (resp. weighted patient-days) as defined under Ad a. are cost oriented. The output unit of a certain hospital however, is not equal to the total costs but to the adjusted number of admissions. It is an index which represents the output of a hospital with respect to other hospitals. The intermediary production is oriented to the tariffs but is not equal to total revenues. Rather it represents the relative position of this output unit with respect to other hospitals. Also the intermediary production is a comparative quantity.
In the definition of weighted admissions the relation is to the number of admissions. This can lead to distortion since it is not the whole hospital that is involved with the admitted patient. But is also involved with outpatient patients. It should be noted however, that the different components of the hospital function, inclusive the outpatient function, are taken into account via the weighing mechanism. The intermediary production definition gives more direct and explicit expression to the different elements of the hospital organization (nursing departments, treatment departments, outpatient department). These are not related to admissions or patient-days.
Although the weighted admissions do not reflect the final output of a hospital, this output unit does have a more final character than the intermediary production.

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1) We note here that a patient day is used differently in the Ad a. output definition (a weighted patient-day) than in the Ad b. definition (intermediary production). When using weighted patient-days, output components (patient care and training programme) are related to patient-days through the described weighing mechanism. When using intermediary production, the patient day is not a denominator to which the output components are related, but it is, next to treatments, one of the production elements.

Both output definitions are relative quantities which represent the positions of the hospital with respect to each other. This fits in with the methodology of our analysis, which is based on the study of the systematic relationships between the differences in outputs and inputs between hospitals. Hereafter, we will compare the analysis results of these two different output definitions.

I.4.2. Definition and measurement of the inputs

The inputs are divided into three categories:
a) capital
b) labour
c) other goods and services.

The measurement of these categories is indicated below.

a) Capital factor

- The number of beds;
  the number of beds is the most important input factor since a large part of the activities, particularly nursing activities, are related to this.
- The facility index;
  the facility index is a quantification for the infrastructure of the hospital . In Van Aert c.s. (1976b) it is said that a bed in a small hospital of 200 beds is something different from a bed in a hospital of, say, 700 beds. There is a great difference in the facilities "around the bed".
  The facility index is a proxy variable for the diversity in the infrastructure. It is less concerned with the quantitative production capacity than with the qualitative.

One can see the number of beds and the facility index as an approximation for the amount of capital deployed. Thus, differences in the historical purchase price of assets are avoided.

b) Labour factor

- Staff;
  the basis for the definition of the staff is the relevance for the production process and so for the output. The civil, domestic and economic-administrative staff categories have no direct significance for the production process as described above, bacause an increase in, for instance, domestic staff will in general not lead to an increase of the output. These inputs are more supporting.
  The staff relevant to the production process is still rather heterogenous. Therefore the following distinction is made:
  a) registered nurses
  b) student nurses
  c) other nursing staff
  d) paramedical staff.

- The number of specialists;
  although most medical specialists are not on the pay-roll of the hospitals, the number of specialists is an important input factor in the patient care process. One can differentiate in this respect between attending specialists and supporting specialists. For this it is desirable to calculate the part-time specialists working in a hospital at any time in terms of a conversion to full-time basis. No information regarding this is available for 1971, but for 1972 and 1973 it is available.

c) *Other goods and services*

- Drugs and dressings.
- Other medical and paramedical means.

All inputs are expressed in physical terms, with the exception of the other goods and services, which are expressed in monetary terms. It seems reasonable to assume that there are no great price differences for these inputs among hospitals. Inputs are defined and measured above. One input is missing: managerial capacities and the degree of expertise of the executive staff and other decision making staff (including medical staff). As will be apparent from what follows, the production function offers the possibility of obtaining insight into the behaviour of hospitals indirectly.

I.4.3. Model specification

In I.3 it was indicated that the production function is estimated directly by correlating the output of hospitals to the inputs. Considering the characteristics of the production structure of general hospitals (see I.2), there will be no, or hardly any, question of simultaneous bias. That is to say, the residual term (the difference between the observed output and the expected output on basis of the model) will not be in relation to the inputs.
In the literature about this, different model specifications for the production function are suggested. Here we will consider two functions (Cobb-Douglas and translog). In Chapter IV further attention will be given to this, and to the CES function.
The Cobb-Douglas production function, which is used the most, with 5 inputs has the following form:

$$Q_j = A_o . X_1^{\alpha 1} . X_2^{\alpha 2} . X_3^{\alpha 3} . X_4^{\alpha 4} . X_5^{\alpha 5}$$

In this: Q_j = hospital output j; j = 1, ..., N
X_1 = staff
X_2 = beds
X_3 = specialists
X_4 = facility index
X_5 = drugs
A_o, α_i = parameters to be estimated ($\sum_{i=1}^{5} \alpha_i = a$)

It is assumed that the number of beds is the most important input, for both the weighted admissions and patient days respectively, as well as for the intermediary production. The output elasticities of the number of beds will be considerably greater than of the other inputs. This will be the case for the weighted patient-days in particular. The number of beds is a much more stringent input for patient-days than for admissions. For a given number of beds the maximum number of patient days is a constant, while the number of admissions may vary with the turn-over rate (number of admissions per bed.) The turn-over rate is determined by the occupancy rate and the length of stay.
Intermediary production will, besides the number of patient-days, determined by the number of treatments. The latter will be only indirectly dependent on the number of beds. The staff and the number of specialists will also be important inputs, although quantitatively less than the number of beds. The facility index is a proxy variable and will not be so much related to the number of admissions as it will to the "weight" of the admissions. It will be noted however, that, in terms of the inputs, the staff (and in particular paramedical and specialized nursing staff) necessary for the exploitation of facilities will be more relevant than the facilities themselves. The (costs of) drugs will be particularly relevant for the intermediary production because the revenues of drugs will be incorporated into this directly.

The Cobb-Douglas production function implies that the output elasticities of the inputs are constant and independent of the input levels. The output elasticity of input i is the percentage of change of the output as a result of 1% change of input i.
When all inputs are increased by λ%, the output increases by

$\lambda^{\alpha_1 + \dots + \alpha_5}$ % $(= \lambda^a)$.

The scale effects are independent of the input levels. If $a = 1$, the input increases by λ%, and we then have constant scale effects. If $a > 1$, the scale effects are advantageous, and if $a < 1$ the scale effects are disadvantageous.
The elasticities of substitution between the inputs are all equal to 1 and are independent of the input levels.

The assumptions on which the Cobb-Douglas specification is based are very stringent and one might ask to what extent they are realistic for the hospital sector.
It does not, for instance, seem realistic to assume that the output elasticities of the inputs are independent of the input levels. It may be expected that the output elasticity of the number of beds, with a fixed number of staff and specialists, will not remain constant, but will decrease.
Also, the substitution possibilities between the number of beds and the number of staff will not, for instance, equal those between the number of beds and the number of specialists. Within the framework of the exploratory nature of this study, therefore a few more generalized models have been examined.

The CES production function, in which the assumptions made, are more general in nature, offered little clarification compared to the Cobb-Douglas production function. The translog production function is the third specification we have tested. The specification of this model with p inputs is as follows:

$$\ln Q = a_o + \sum_{i=1}^{p} a_i \ln X_i + \sum_{i \leq j} b_{ij} \ln X_i \ln X_j$$

In the translog model the output elasticities and the substitution elasticities are dependent on the input levels. The substitution elasticities between inputs do not have to equal each other.
Just as the scale effects for the Cobb-Douglas model are constant over the whole range, with the translog model it is assumed that they are dependent on the input levels.
The Cobb-Douglas model is a special form of the translog model; when all b_{ij} coefficients are zero, the result is the Cobb-Douglas function.
The results of the estimates and the performed tests indicate that the translog specification is more suited to the data than the Cobb-Douglas or the CES specifications.

I.5. Estimation of some production functions for general hospitals

In this section we will consider a few model estimates of the translog specification. We are assuming 5 inputs, and the outputs are in terms of the weighted admissions and intermediary production respectively. The definition of the variables is given in Appendix I.1. The data comes from at least 100 general hospitals in 1971, as included in the BKZ data-base.
Model 1 gives the estimation results of the production function for the weigted admissions; model 2 for the intermediary production (table 1).
The explanatory power of the models is very high. That is to say, one can with the aid of the 5 inputs (staff, beds, specialists, facility index, drugs) explain a very large part of the differences in the (ln) weighted admissions (94%) and the (ln) intermediary production (99%) respectively.

When the parameter estimates are examined only a small number of coefficients are significant ($\hat{a} > 2\hat{\sigma}_{\hat{a}}$).
This is related to the correlations between variables in the sample (multi-collinearity). This is particularly true for the linear, quadratic and the cross terms per input.
More insight into the significance of the influence of the inputs may be obtained by examining the output elasticities and the related standard deviations (table 2).

Table 1: Estimated production functions for 5 inputs and the number of weighted admissions and the intermediary production respectively (double logarithmic specification).

	weighted admissions (1) estim. coeff.	estim. stand. dev.	intermediary production (2) estim. coeff.	estim. stand. dev.
1. Constant	5,29	7,29	15,26	3,34
2. Staff	-2,75	3,43	0,53	1,56
3. Beds	6,23	3,61	0,18	1,65
4. Spec.	1,39	1,88	0,60	0,86
5. Fac.	-0,35	1,27	0,64	0,58
6. Drugs	0,03	1,21	-0,90	0,55
7. $(\text{Staff})^2$	-0,17	0,74	-0,71	0,35
8. $(\text{Beds})^2$	-0,84	0,91	-0,96	0,42
9. $(\text{Spec.})^2$	-0,26	0,23	0,13	0,11
10. $(\text{Fac.})^2$	0,040	0,079	0,051	0,036
11. $(\text{Drugs})^2$	0,023	0,068	0,021	0,031
12. Staff * Beds	0,35	1,47	1,42	0,69
13. Staff * Spec.	0,12	0,60	-0,029	0,274
14. Staff * Fac.	-0,058	0,31	0,26	0,15
15. Staff * Drugs	0,20	0,37	-0,076	0,170
16. Beds * Spec.	1,23	0,70	0,25	0,32
17. Beds * Fac.	0,10	0,39	-0,39	0,18
18. Beds * Drugs	-0,15	0,35	0,26	0,16
19. Spec. * Fac.	-0,28	0,22	-0,029	0,099
20. Spec. * Drugs	-0,29	0,19	-0,11	0,08
21. Fac. * Drugs	0,061	0,123	0,006	0,056
R^2	0,94		0,99	
N	107		104	
$\bar{R}^2$	0,93[1)]		0,99	

1) $\bar{R}^2 = 1 - (1 - R^2)\left(\frac{N-1}{N-k-1}\right)$

N = number of hospitals; k = number of variables

The output elasticity of a certain input (e.g. staff) is based not only on the estimated coefficient of "staff" from table 1, but also on the estimated coefficients of $(\text{staff})^2$, staff x beds, staff x spec., and staff x drugs.
In the calculation of the standard deviation of the output elasticity of the staff, the standard deviations of all the variables mentioned are incorporated along with the correlations between the respective estimates.

Table 2: Output elasticities of the inputs for weighted admissions and the intermediary production respectively, based on average input levels.

	weighted admiss.		interm. production	
Inputs	elast.	σ	elast.	σ
Staff	0,34**	(0,15)	0,22**	(0,06)
Beds	0,64**	(0,15)	0,68**	(0,06)
Drugs	0,04	(0,05)	0,15**	(0,02)
Spec.	0,02	(0,08)	-0,02	(0,04)
Fac.	0,00	(0,07)	0,02	(0,03)

** t-statistic > 2.

For both the weighted admissions and the intermediary production the number of beds has the highest output elasticity, 0,64 (σ = 0,15) and 0,68 (σ = 0,06) respectively. With an increase of the number of beds by 1% the number of weighted admissions increases by 0,64% and the intermediary production increases by 0,68%.
For the weighted admissions, assuming the average values of the input levels, the other output elasticities are not significant. The output elasticity of the drugs for the intermediary production is 0,15 (σ = 0,02). At this point a certain tautology may be present because the revenues from drugs are incorporated into the intermediary production. If all inputs increase by 1% the weighted admissions will increase by 1,04% (σ = 0,06) and the intermediary production will increase by 1,05% (σ = 0,03). On this basis we may -assuming average input levels- draw the conclusion that there are advantageous scale effects (economics of scale). When we do not assume average input levels we see certain shifts taking place in output elasticities. In the next section we will come back to this point.
From a number of statistical tests there are indications that a translog specification suits better to the data than a Cobb-Douglas specification.

I.6. Interpreting production function estimates

We will consider the results in the light of the following economic characteristics:

a) output elasticities
b) scale effects
c) elasticities of substitution
d) output, input, and cost indices

The nature of the production function

In these interpretations the nature of the estimated production function should always be taken into consideration.
The estimated production function has a "behavioural" nature, that is to say, it represents the average tendencies as they were present in 110 hospitals in 1971. It is therefore not a production function in the sense of the line of the most efficient production possibilities. On the basis of the estimated production function it is, however, quite possible to obtain some insight into a production technique that is more efficient than the average. Using the residuals of the estimated "average" production function of "all" hospitals, we can select 50 hospitals that show a higher-than-average "efficiency". Subsequently, on the basis of these hospitals a new production function can be estimated. From these estimates it can be concluded that the production function based on the 50 selected hospitals is a more efficient function in the sense that more output is achieved while the inputs remain the same (Appendix I.2).
Thus, assuming the average of inputs (i.e. an average number of staff, beds, specialists, etc.) it can be calculated that, according to the "more productive" model, about 13% more output may be achieved than according to the model based on all hospitals. This means that when the less productive hospitals would produce like the more productive hospitals, their output would be on average increased by about 25%.
It should be noted that, with respect to a number of key variables, the (50) more productive hospitals deviate only slightly in comparison to the other (less productive) hospitals. One might consider for instance patient characteristics (degree of despecialization, % ENT), the number of beds, training programme, year of construction, ownership etc. From the point of view of these variables there are no great differences between the 50 more productive and the 57 less productive hospitals.

a. *Output elasticities*

a.1. Weighted admissions

The output elasticity[1] of the number of beds is 0,64. That is to say, the output will increase by 0,64% when the number of beds increase by 1%. The output elasticity of the staff (nursing and paramedical) equals 0,34.

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1) The marginal productivity of input i is the first derivative of the production function with respect to input i $(\frac{\partial Q}{\partial X_i})$

By multiplying this by $(\frac{X}{Q})$ one obtains output elasticity of input i. In our specification of the translog production function the output elasticity is the first derivate of this function, i.e. $\frac{\partial \ln Q}{\partial \ln X_i} = \frac{\partial Q}{\partial X_i} \cdot \frac{X_i}{Q}$

These results have a small confidence interval when one considers the relationship between the estimated coefficients and the estimated standard deviations. Based on the average hospital, the other inputs (specialists, facility index, drugs) have no significant influence on the output. When there are deviations from the average input levels, other elasticities are obtained, because the production function we have chosen allows the output elasticities to be dependent of the input levels. Our basis is the average of the input levels of the function groups as indicated in Van Aert en Van Montfort (1976).
For the weighted admissions, the output elasticity of the staff increases from 0,18 (σ = 0,19) in function group I to 0,51 (σ = 0,27) in function group IV. With respect to the number of beds we see the opposite, a decrease form 0,82 (σ = 0,19) in functiongroup I to 0,52 (σ = 0,26) in function group IV. The output elasticity for the number of staff is therefore higher in larger hospitals than in smaller hospitals. In this the difference in function (patient care and training programmes) among the hospitals have been taken into account. The output elasticity of the number of beds is lower in the larger hospitals than in the smaller ones. It will be noted that we are here concerned with the differences between function groups. The development of output elasticities within function groups will be discussed on page 27. In a model where the staff is divided into a number of categories, we see variations in the curve of the output elasticities of the different staff categories within the function group.
In function group I registered nursing staff is more relevant than the student nursing staff. In function group IV the opposite is true. With a given number of beds, more staff (and in particular registered nursing staff) will result in a shorter length of stay. In the larger hospitals the use of more staff and in particular student nursing staff will in terms of weighted admissions be more productive than in small ones.

a.2. Intermediary production

For intermediary production the average output elasticity of the number of beds equals 0,68 (σ = 0,06). That is to say, the intermediary production will increase by 0,68 with a 1% increase in the average number of beds. The output elasticity of the staff is 0,22 (σ = 0,06). As is the case with the weighted admissions, the number of beds is the most important factor for the intermediary production as well. This implies that in the functioning of the hospitals the number of beds is an essential factor, but not a predominating one.
When we view the elasticity with respect to intermediary production per function group, there are differences between the function groups for staff and for drugs. In function group I the output elasticity for the number of staff members equals 0,30 (σ = 0,09) and in function group IV it equals 0,14 (σ = 0,12). The output elasticity of the number of beds shows small differences between function groups.

The output elasticity for drugs in function group I equals 0,10 (σ = 0,03) and in function group IV it equals to 0,18 (σ = 0,04). Productivity in terms of the intermediary production of the staff is higher in the smaller hospitals than in the larger hospitals. For drugs we see that the opposite is true. This implies that the same percentage increase in drugs will result in a greater increase in intermediary production in function group IV hospitals than in function group I hospitals. In the hospitals with a more complicated function level, there is a relatively greater use of drugs.

The use of the model with separate staff catagories allows for some nuances in this. On the basis of the average inputs levels the paramedical staff has a significant output elasticity (0,25, σ = 0,09).
When the output elasticities are calculated per function group, we can discern a path for paramedical, registered nursing, and student nursing staff. The output elasticity of paramedical staff in function group I equals 0,13 (σ = 0,08) and in function group IV it equals 0,29 (σ = 0,12). The paramedical staff thus has a greater influence on intermediary production in the larger, more complicated hospitals. For the registered nursing staff the opposite is true. The output elasticity in function group I (0,21, σ = 0,11) is higher than in function group IV (0,10, σ = 0,14). It should be noted here that on the basis of a relatively high σ in function group IV, no great statistically significant differences can be concluded.
In function group I the student nursing staff has a lower output elasticity (0,02; σ = 0,09) than in function group IV (0,13; σ = 0,09), although this is not very significant.

Apart from a comparison of output elasticities at average input levels per function group, we can also examine the path within each function group. For weighted admissions, it is apparent that with an increase in the number of beds, taking into account the range of input ratio's within a function group, the output elasticity of the number of staff members and the number of specialists increases. The output elasticity of the number of beds, however, decreases.
Thus, with a tighter allocation of staff per bed, the marginal productivity of the staff is higher than with a greater allocation of the staff per bed.
This is particularly true for registered, and to a lesser degree for the student nursing staff. Such a conclusion can also be drawn with respect to the number of specialists. With a larger number of beds per specialist, the increase of the number of weighted admissions with respect to the increase in the number of specialists will be larger.
In other words an increase in the number of beds, at a small number of beds per specialist, will lead to a greater increase in the number of weighted admissions than with a larger number of beds per specialist.
To the extent that specialists have a smaller number of beds available, these will, in terms of weighted admissions, be used more intensively.

In the grafics 2 through 5 the changes in output elasticities of the number of staff members, the number of beds, and the number of specialists are represented graphically. This is done on the basis of the average levels per function group of the number of staff members, the number of specialists, the facility index, and the drugs. The number of beds is varied within the input ratio's of the related function group. From this it can be concluded that per function group the output elasticity of the number of beds decreases with a greater number of beds (law of deminishing returns[1]). These diminishing returns also hold true for the other inputs. In grafic 6 the changes in the output elasticities of the staff and the number of beds between and within function groups are compared. This is done on the basis of differing levels of the number of staff members and the number of beds respectively. The levels of the other inputs are kept constant at the average level per function group.
From grafic 6 it may be concluded that for both the number of beds and the number of staff members within the function groups there are diminishing returns. Between the function groups there are differences in levels of output elasticities. For the number of beds there is a small decrease of the average output elasticities from function groups I through IV. For the staff we see an increase of the average output elasticities from function groups I through IV.
This seems contradictory to the increase of the staff per bed from function group I to function group IV since one might conclude from this that the output elasticity of the staff would decrease because of the greater use of staff.
One cannot, however, automatically view the change of the output elasticity of certain inputs over the whole range; one must assume certain input levels (e.g. averages of function groups) and the empirically existing input ratio's.
We can see a change in certain output elasticities within the function groups in the intermediary production as well. The marginal productivity of the number of beds increases at higher levels of staff. This is particularly true for registered nursing staff. The productivity of beds with respect to intermediary production increases with an increase in the number of specialists. This tendency is stronger in function group III and IV hospitals. The productivity of the staff increases at higher levels of the facility index within a certain function group.

A comparison of the output elasticities with respect to weighted admissions and intermediary production leads to the conclusion that the paramedical staff -particularly in function groups III and IV hospitals- is more relevant for the intermediary production than for weighted admissions. The influence of the number of specialists is greater for the weighted admissions than for the intermediary production.

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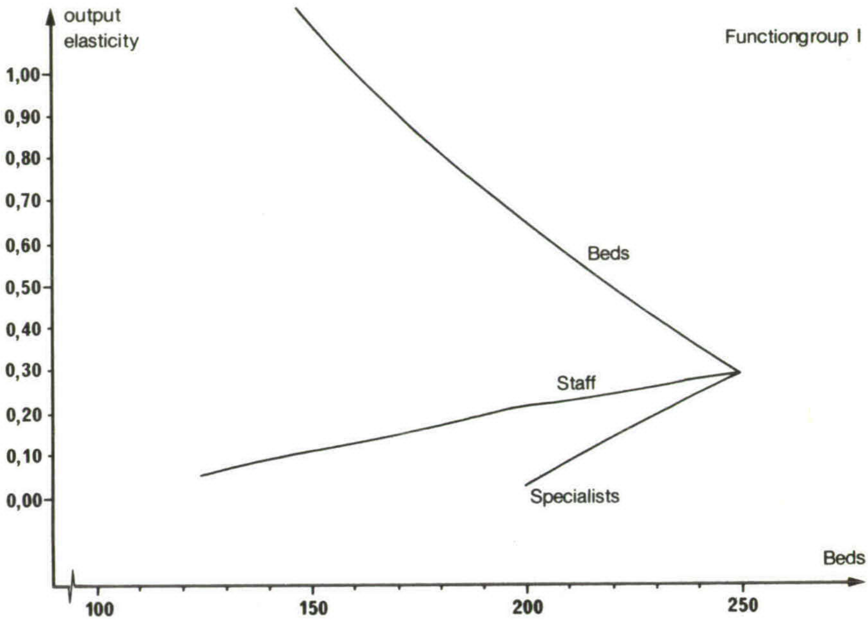
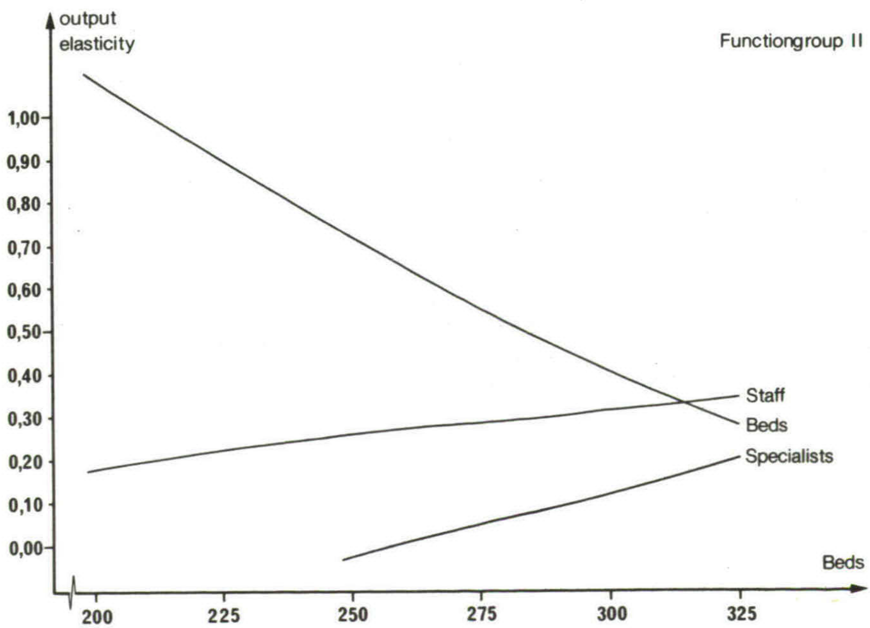
[1] In this context Samuelson (1978) uses the term the "law of diminishing marginal-physical-product".

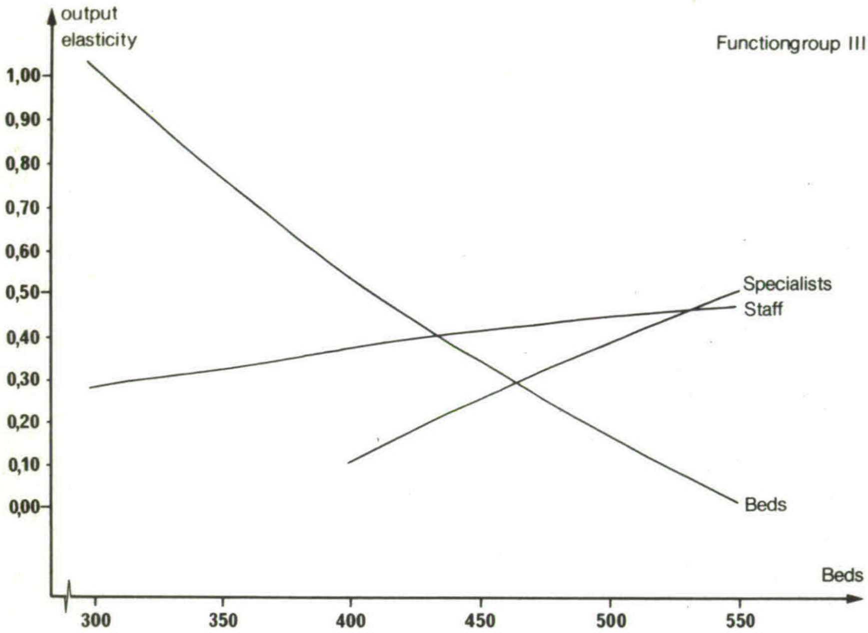
Grafic 2: Curve of some output elasticities in functiongroup I at different levels of the number of beds.



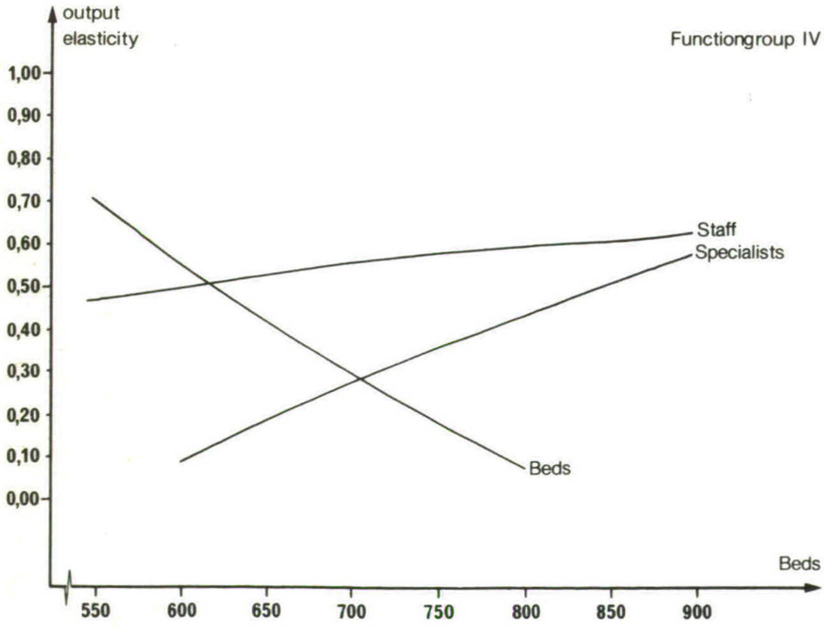
Grafic 3: Curve of some output elasticities in functiongroup II at different levels of the number of beds.



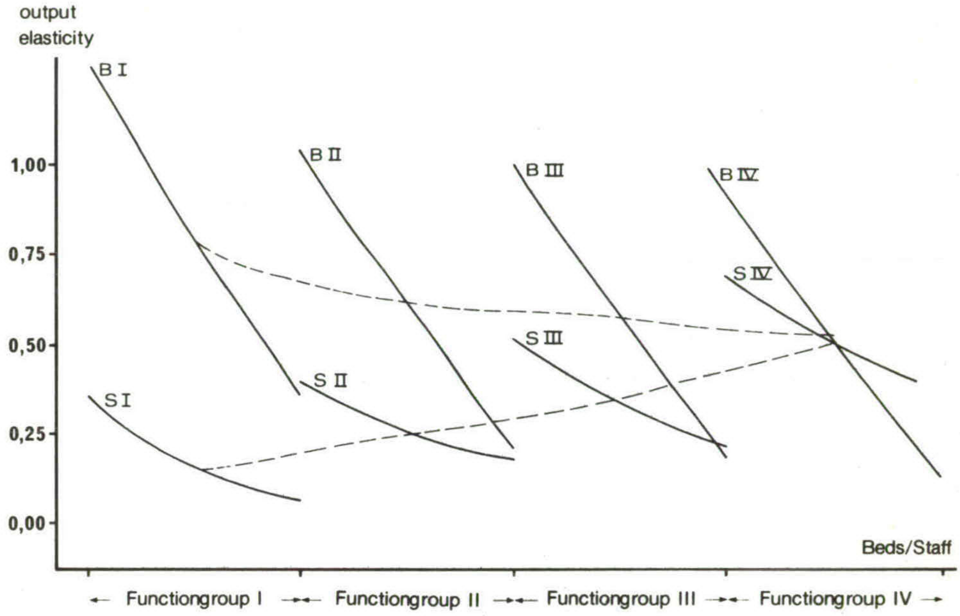
Grafic 4: Curve of some output elasticities in functiongroup III at different levels of the number of beds.



Grafic 5: Curve of some output elasticities in functiongroup IV at different levels of the number of beds.



Grafic 6: Output elasticity of beds and staff per functiongroup at different levels of beds (B) and staff (S)



The registered nursing staff is more relevant for the weighted admissions than for the intermediary production. These differing results, with respect to weighted admissions and intermediary production respectively, point to the difference in concept between these two output definitions.
To conclude the discussion about output elasticities, we make a few comments regarding the manner of calculation of the number of specialists and the consequences thereof for the estimates.
With regard to the number of specialists, no conversion has been made for full-time or part-time jobs. From models of a group of hospitals for which this information was available, it appears that the estimates of the other coefficients in the model for weighted admissions is not influenced by this. The estimated parameter of the number of adjusted specialists was significant. The output elasticity for the total number of adjusted specialists with respect to weighted admissions equals 0,27 (σ = 0,09).
This implies that an increase in the number of adjusted specialists by 1% in an average hospital leads to an increase of weighted admissions by 0,27%. Furthermore, a distinction was made between specialists who are directly involved with patient-care (attending specialists) and those who are indirectly involved with the patient (supporting specialists). From the output elasticities it appears that, as one might expect, the attending specialists are more relevant for the output in terms of weighted admissions than are the supporting specialists.
The length of stay plays a more important role in weighted admissions than in intermediary production. From Van Aert et al. (1977) it is apparent that there is a significant relationship between registered nursing staff and the length of stay. With other staff catagories this is much less so. Additionally, in the following, the conclusion is drawn that the results do not bring forth any indication pointing to a substitution between patient days (length of stay) and medical treatments, which will be particularly related to the para-medical staff.

b. Scale effects

One of the characteristics of the production structure concerns scale effects. This indicate to what degree, in the sense of technical production, it is advantagious or dis-advantagious to produce on a larger scale. Scale effects can be measured by the sum of the output elasticities. If the sum of the output elasticities is geater than 1 then there are advantageous scale effects (economies of scale). That is to say, assuming the average production structure, the output increases by more than 1% when all inputs increase by 1%.
If the sum is less than 1%, there are disadvantageous scale effects (diseconomies of scale).
Naturally, the scale effects may depend on the output unit used.

For weighted admissions, there seems to a limited degree economies of scale (1,04%; σ = 0,06). The economies of scale becomes greater with an increasing scale, though this is not very significant. In hospitals belonging to function group IV (1,10%; σ = 0,11) the economies of scale or a little bigger than in function group I hospitals (1,01%; σ = 0,09). On the basis of the intermediary production we can draw the conclusion that there are to a limited dégree economies of scale (1,05%; σ = 0,03). In function group IV the economies of scale ara a little bigger (1,07%; σ = 0,05) than in function group I (1,02%; σ = 0,04). These differences are, however, not significant.
The general conclusion may be that with respect to both weighted admissions and intermediary production, the scale effects are small in the utilisation of inputs. The conclusions with respect to scale effects are not contradictory with the results based on the cost function. For the cost function it was concluded that, with the exception of function group IV hospitals, scale effects were not, or were hardly, present (Van Aert, 1977). After a certain size in function group IV hospitals, there are negative scale effects; this is in particularly so with respect to management costs (executive and administrative staff). This last factor is not included in the production function because this does not play an essential role in the transformation process.

c. Elasticities of substitution

The elasticity of substitution indicates to what degree it is possible, given a certain output level, to replace one input for another.
The elasticity of substitution is the relationship between the marginal rate of substitution of 2 inputs, and the change in the ratio of the levels of the 2 inputs. Thus, it indicates the degree to which it is necessary to adjust the input ratio to obtain the same output when a change occurs in the marginal substitution rate of two inputs.
In the interpretation of the elasticities of substitution -as is the case for the other results- one should keep in mind that these are based on an analysis of the differences in outputs between hospitals in a certain year. These do not then, indicate how over a period of time a hospital might substitute one input for another. They do indicate how in practice, hospitals with differing input ratio's realize a certain average output level. The presence of substitution possibilities does not, however, impair the special responsibilities for examination and treatment of patients.

The translog function allows that elasticities of substitution between inputs to be different and dependent on the input levels. From the elasticities of substitution as calculated on the basis of the different translog models, it may be concluded that there are, to a limited degree and with little statistical significance, substitution possibilities between certain inputs.

With respect to weighted admissions, there are substitution possibilities between the staff (particularly student nursing and the other nursing staff, and the paramedical staff) and the number of beds, and between the staff (particularly registered, student and other nursing staff) and the number of specialists.
Within the defined staff catagories there are substitution possibilities present between registered nursing and other nursing staff, and between student nursing and other nursing staff. To a lesser degree substitution is also possible between registered nursing and student nursing staff, and between student nursing and paramedical staff.
This implies for example, that the same output (in terms of weighted admissions) may be achieved with different input combinations.
With respect to the intermediary production, substitution is possible between (student nursing) staff and the facility index. The facility index is particularly related to the treatments. The correlation between the facility index and the percentage of revenues from treatments in the total intermediary output is 0,56.
The student nursing staff is particularly related to the patient days (occupancy rate). Thus, this substitution is connected to shifts within the intermediary production.
There are also substitution possibilities between the other nursing staff and the paramedical staff and between the paramedical staff and the number of beds.

With respect to the statistical significance of the results it is not possible to draw very exact conclusion about the magnitude of the elasticities of substitutions. We have very broad confidence intervals. It seems difficult to draw specific conclusions on the basis of the available data.
It is possible that the behaviour of hospitals and specialists is not systematic with respect to substitution possibilities or that it is very difficult to adjust the input levels.
Further research into the substitution possibilities is very important. Findings may be meaningful within the framework of planning, particularly when the production functions can be actualized with data from recent years. In planning one will not only be concerned with the number of beds (be they differentiated according to functio, or not), but also with the other inputs. This implies that there may not only be substitution between extramural and intramural care[1] but also that there are more production possibilities within the intramural sector.

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1) From certain studies (Rutten et al., 1975; v.d. Gaag, 1978 and Rutten , 1978) it is apparent that expansion of the first echelon of the health care system (in particular the number of family doctors) can absorb a decrease in the number of beds in hospitals per 1000 inhabitants. Hoeksema (1979) has compared a large number of, mainly Dutch, studies in the area of the relationships between first and second echelon. He concludes that these studies contradict each other on this point.

Depending on local (regional) factors and price ratio's, one will have to take into account in the planning process all inputs (e.g. staff, specialists, beds, facilities) and the expected developments therein. It will then also be possible to coordinate long term and short term planning. With low marginal costs per admission (Van Aert, 1977) it might be cheaper to keep the allocation of staff on existing beds (short term) tight, while the beds in new buildings (long term) might be kept tight, with a relatively more generous allocation of staff.
Van Aert and Van Montfort (1978c) calculate for two hospitals the cost increase when a hospital change from old buildings to new buildings. Taken into account the hospital function they see no significant increase in the salaries, but high increase in other cost catagories.

As is apparent from many studies (Rutten et al., 1975; Fokkens, 1968; NZI, 1973) the number of admissions and the number of patient days per 1000 inhabitants strongly depends on the number of beds per 1000 inhabitants in a region. Feldstein (1967) and Vaananen (1974) also reach this conclusion for the British and Finish hospital sectors, respectively. Rutten et al. have found that with a higher density of beds, the admission coefficients is higher than with a lower density of beds (availability effect). This relation is built up from two effects. There is a direct (increasing) effect of the density of beds on the admission coefficient and an indirect (decreasing) effect. This indirect effect is the result of the longer length of stay (and thus relatively fewer admissions) at a greater density of beds.
In our study, the position of the hospitals within the region is not explicitly included. Our results do, however, also point to the great importance of the beds factor. Additionally, however the size of the staff and the number of specialists (adjusted in terms of a full-time basis) are also relevant for the output in terms of the weighted admissions and the intermediary production. Later on we will return to the results of the production function within the framework of the regional situation.

d. Output, input and cost indices

With the aid of the production function it is possible to construct an output index per hospital. This is defined as the observed output (or production) divided by the expected output.
The expected output (production) of a hospital is the output that would have been reached with the given input levels of that hospital, if production has been realised according to the production function (average production technique of the sector).
It is also possible to derive a relationship between the output index and the cost index as derived (Chapter V) on the basis of the cost functions (Van Aert, 1977):

$$C_i = \frac{1}{O_i * I_i}$$

Whereby: C_i = cost index of hospital i;
observed costs divided by expected cost of hospital i on the basis of the cost model.

O_i = the output index of hospitals i;
observed output of hospital i divided by the output expected on the basis of the production function.

I_i = the input index;
this index is derived from the above formula. This index contains elements, such as deviations on the input price, the efficiency by which inputs not included in the production function are allocated, etc.

First we will be concerned with the output index and thereafter with the relationships between output index, cost index, and input index.

Output index[1)]

The output index of hospital i is the observed output divided by the expected output.
An output index greater than 1 indicates that hospital i has attained a higher output level (e.g. more weighted admissions) with the given inputs than would have been achieved according to the production function. Studying the output indices in relation to a number of factors may provide insight into the behaviour of hospitals.

Table 3: Frequency distribution of output indices with respect to weighted admissions (O_i).

	number of hosp.	%
$o_i \leq 0{,}85$	11	10,5%
$0{,}85 < o_i \leq 0{,}90$	18	17,1%
$0{,}90 < o_i \leq 0{,}95$	9	8,6%
$0{,}95 < o_i \leq 1{,}00$	17	16,2%
$1{,}00 < o_i \leq 1{,}05$	20	19,0%
$1{,}05 < o_i \leq 1{,}10$	9	8,5%
$1{,}10 < o_i \leq 1{,}15$	3	2,9%
$o_i > 1{,}15$	18	17,1%
Total	105	100%

1) The output indices are based on the translog production.

From the frequency distribution of output indices (table 3) it can be deduced that about half of the hospitals have an output index above and below 1, respectively. Considering the nature of the analysis, this is to be expected. About 17% of the hospitals have an output index more than 15% above 1.
This means that 17% of the hospitals produce more than 15% more output with the given inputs than according to the production function. These hospitals are thus "more productive" in terms of weighted admissions, than the "average" hospital. One can also conclude that about 10% of the hospitals have more than 15% less output than according to the production function.
With respect to the intermediary production, the output indices per hospital can also be calculated. The frequency districution of these output indices shows an analogous picture, although the spread is somewhat less. The correlation between the output index of weighted admissions and that of intermediary production is 0,37. This correlation implies that hospitals that with given inputs achieve a relatively high intermediary production, do not systematically have a relatively high number of weighted admissions. That is not to say that hospitals with a high intermediary production do not have a high number of weighted admissions. But output indices concern the level of output, given the inputs.
These findings point to conducting a study at the micro level of the treatment of patients in more "extreme" hospitals. A comparison can then be made how the available inputs are utilized at the patient level in these hospitals. In this manner indications may also be obtained how, from the point of view of technical production, a synthesis can be made between macro econometric studies and micro studies at the patient level.
These two approaches are not divorced, but can be used to supplement each other, since the treatment of patients occurs withing a certain institutional structure.
This implies that the treatment of patients will be influenced by the institutional structure and, conversely, that the institutional structure will be adjusted (both on a short and a long term basis) to changes in the treatment of the patients.

Output indices and hospital characteristics

Using a number of correlations, we will more closely examine the meaning and interpretation of the output indices of the weighted admissions and the intermediary production (tabel Chapter V).
It may be concluded that there is no or only little relationship between the number of beds, the training programme for specialists, the facility index, the year of construction, and the ownership on the one hand, and the output indices on the other.
The output indices of large hospitals, which in general have a broader function, do not on average deviate from the other hospitals. Conversely, one might also state that the factors regarding the hospital function are well-represented in the output definitions. If we view the output indices per function group, it is apparent that there are no differences among the function groups.

It may be deduced from this that the output differences between function groups are also well-represented in the output definitions. There are, after all, great differences in the outputs between function groups, considering the definitions of the function groups (table 10).

Output indices, length of stay and occupancy rate

The output indices are related to the productivity with which inputs are utilized. A relatively more intensive use will imply a higher output index, and vice versa.
In evaluating the differences in use of the inputs, the regional context must also be taken into account.
The length of stay and the occupancy rate are variables that give an indication of the use of the inputs. It is noted that the occupancy rate is only related to the occupancy of beds, and not to the other capacities (treatment department, outpatient clinic).
A number of correlations are represented in table 4.

Table 4: Output indices, length of stay and occupancy rate.

Variables		1	2	3	4	5	6	7
Output index:								
weighted adm.	(1)	1						
interm. prod.	(2)	.37	1					
Length of stay	(3)	-.55	-.09	1				
Adj. length of stay	(4)	-.70	-.10	.88	1			
Exp. length of stay	(5)	-.12	-.09	.44	.19	1		
|3-5|	(6)	-.54	-.25	.71	.77	-.32	1	
Occupancy rate	(7)	.38	.45	-.01	-.06	.02	-.35	1

The (adj.) length of stay is closely related to the output index of the weighted admissions and has no relation with the output index of the intermediary production.
The correlation of the output index of weighted admissions and the average length of stay is -.55, and with the adjusted length of stay (excluding ENT patients) it is -.70. The difference between these two correlations once more points to the fact that the ENT effect has been calculated in the output definition of weighted admissions, for the difference between the average length of stay and the adjusted length of stay is equal to the percentage of ENT patients. From the high correlation with the adjusted length of stay, it appears that the differences in the output index of the weigthed admissions are, for about fifty percent, related to the differences in adjusted length of stay (i.e. $0{,}70^2 = 0{,}49\%$).

How are these relationships to be interpreted?
Thereby we arrive at the point of the instrumental nature of the (adjusted) length of stay.

In this connection it is interesting to examine the expected length of stay. This is calculated by the SMR[1], whereby the age of patients, the diagnosis, cooperated treatment and operations are explicitly taken into account. This indicates that the expected length of stay is an important indicator of the patient population. The correlation with the output index of the weighted admissions is -.12. In other words, the expected length of stay is implicitly calculated in the output definition. Therefore it is interesting to consider the relationship between the output index and the difference between the observed and expected length of stay. The correlation is -.54. A larger, positive difference between the observed and expected length of stay is related to a lower output index, and thus to a lower productivity. This means that in that case, with the given inputs, relatively fewer weighted admissions are treated. Van Aert (1977), too, is of the opinion that significance may be attached to the difference between the real and the expected length of stay in comparing the productivity of hospitals.
From this, it may be concluded that the length of stay, viewed by means of the difference between the real and the expected length of stay, has to some degree an instrumental nature. The fact that lenght of stay for many categories of patients has shown a decreasing tendency over recent years is also indicative for the -in any case partially- instrumental nature of the length of stay.
Also an argument for the instrumental nature of the length of stay are the correlations between the output index and a number of variables such as the operation index ($\rho = +.19$), and the percentage of emergency cases ($\rho = +0.04$). These specific patient characteristics have no relation with the output index (chapter V).
Separate attention must also be paid in this connection to the relationship between the output index and the production on the treatment departments. The correlation between the output index of weighted admissions and the number of activities per 100 admissions are all low, which implies that the differences in this output index do not show any relationship with the differences in the number of activities per 100 admissions. From Chapter V we can conclude that there are strong relations between the weighted admissions (output) and the number of treatments per 100 admissions.
From these correlations it may also be concluded that there are no indications for substitution between length of stay and activities in the treatment departments. More insight into this may be obtained by examining the intermediary production. Patient days and outpatient visits (intermediary production) are produced for the examination and treatment of patients. The correlation between the output index of the weighted admissions and the intermediary production is 0.37. This relationship implies that hospitals, that with their given inputs achieve a high output in terms of weighted admissions, do no systematically achieve a high output in terms of intermediary production.

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1) For an exact definition the reader is refered to Nationaal Ziekenhuisinstituut (1975) and Gemert (1973).

The coefficient of variation of the output index of the weighted admissions (0,14) is considerably higher than the coefficient of variation of the output index of the intermediary production (0,06). This can be related with the structure of norms and guidelines of the COZ, which are related to the number of patient-days and treatments and not to the weighted admissions.
The results indicate that the intermediary production is more closely related to the inputs, than the weighted admissions (patient care and training programme) which is, conform the scheme in chapter III, a more final object of the hospital than the intermediary production.
The correlation of the output index of intermediairy production with the length of stay, as well as with the expected length of stay is -0.09. The latter means that there is a systematic relationship between the intermediary production and the patient characteristics as they are included in the expected length of stay.
Also the correlation between the output index of the intermediary production and the difference between the observed and expected length of stay is low ($\rho = -.25$).
This implies that the variation in the intermediary production, given the inputs of the hospitals, shows little or no relationship with the different length of stay variables.

The occupancy rate in the evaluation of the allocation of the inputs is an important factor, though relatively less so than the length of stay. This is related to the small differences in occupancy rate between the hospitals when compared to the length of stay variables.
The correlation of the output index of weighted admissions with the occupancy rate is .38, and that of the occupancy rate with the intermediary production equals .45.
A higher productivity, in terms of both weighted admissions and intermediary production is related to a higher occupancy rate.

Output indices and the regional situation

The cause of the differences in the output indices can be the quality of care, the efficiency, and the location of the hospital in the region, and as an extension of this, the supply and demand relation. It is noted that all these factors do not operate independently of each other. Here we will pay attention to one of the regional aspects. To obtain better insight into the possible relationships between the output index and the place of the hospital in the region, we will define the bed density of the hospital and the admission index of the hospital. The bed-density is defined as the number of beds of the hospital divided by the population adherent to the hospital. The admission index is the sum of the admission coefficients of the municipalities, weighted with the percentage of the admissions of the hospital from the municipalities concerned. The correlation between the output index and the bed-density equals -.60. This implies that a higher output index often corresponds to a lower bed-density. In other words, when the bed-density is lower, the beds will, in terms of weighted admission, be utilized more intensively.

As is apparent from the studies by Van Praag et al. and Feldstein, the bed-density has two effects: the admission effect (more beds per 1000 inhabitants is connected to a higher admission coefficient), and a length of stay effect (more beds per 1000 inhabitants is connected to a longer length of stay). The correlation between the bed-density and the admission index equals .59, and that between bed-density and length of stay equals .66. A higher bed-density is related to a higher admission index and a longer length of stay. The correlation between output index and admission index equals .08. This means that the admission effect of the bed-density is implicitly included into the estimation of the production function.

The correlation between the output index and the length of stay is -.70. The bed-density thus affects the output indices more via the lenght of stay and less through the direct admission effect. This does not mean that, if the bed-density is higher in one region than in another region, the admission index will not be higher. For the correlation between the bed-density and the admission index is .59. It does mean that there are relatively fewer weighted admissions per bed. By these results it might be suggested that the admission index is more closely related to the capacity ("availability effect"), and that the length of stay is more related to the specific medical policy, given the capacity. The variations in the output index indicate that with respect to this last aspect, there are differences. Data from the SMR (Medical Registration Foundation) and the LISZ (informationsystem of the sick funds) also support this conclusion.
With respect to the availibility effect, many studies emphasize the number of beds. From the results of the production function it appears that the number of staff and the number of specialists (converted on a full-time basis) should also be included. One might deduce from this that in the planning-process the number of staff and the number of specialists should also be looked at, in addition to the number of beds.

Relationship between output index, cost index and intput index

In Van Aert et al. (1976a) a cost index has been constructed which is the relation between the observed costs and the costs as expected on the basis of the cost model.
On the basis of the formula on page 35 , the input index can be calculated from the cost index and the output index.
We will first concentrate on the output indices with respect to weighted admissions.

One point of consideration is whether one should take into account the concept for cost models used. In the model for the costs per admission, the adjusted length of stay is an important explanatory variable, as is, to a lesser degree, the occupancy rate. The cost effects of differences in the adjusted length of stay are not included in the cost index. As we can see in table 4 the (adjusted) length of stay plays an important role in the output index for weighted admissions.

As indicated above, the length of stay has to some degree an instrumental nature. This indicates that the length of stay should also affect the cost index, which means that the length of stay should be eliminated from the cost model. In an analogous way, the occupancy rate may also be eliminated. Table 5 contains some information regarding O, C and I. The averages of the indices are -considering the definition- just about equal to 1. The variation of the indices differs somewhat. The variation of C (σ = 0,16) is somewhat greater than that of O (σ = 0,14) and I (σ = 0,13).

Table 5: Correlations between output index of weighted admissions (O), costs index (C), and the input index (I).

	O	C	I
O	1		
C	- .61	1	
I	- .20	- 0,56	1
Average	1,01	1,00	1,01
Standard-deviation	0,14	0,16	0,13

We will clarify the meaning of the indices with the use of a certain hospital. According to Feldstein (1967b) the cost index is related to a total (cost) evaluation of the hospital, while the output index and input index are components thereof.
The cost index of hospital A is 0,77, which means that, on the basis of the cost model, this hospital functions with relatively lower costs than the average of the hospital sector. In other words: hospital A has a relatively favourable cost position. The output index (O) of the hospital is 1,03. This implies that hospital A with her inputs has achieved a relatively slightly higher output than the average of the sector. Hospital A has thus with its inputs produce slightly more weighted admissions than the "average" hospital (better utilization of inputs). Here we should realize that with the number of weighted admissions, not only are the number of admitted patients taken into account, but also the function of the hospital through the type of patients (degree of despecialization and the percentage of ENT-patients) the training programme and the outpatient variable.
The input index for hospital A, derived from the cost index implies that this hospital is in a relatively favourable position also with respect to components of the cost index that are not incorporated into O (1,26).

Figure 1: Plot of the cost-index (C) and the outputindex of weighted admissions (O)

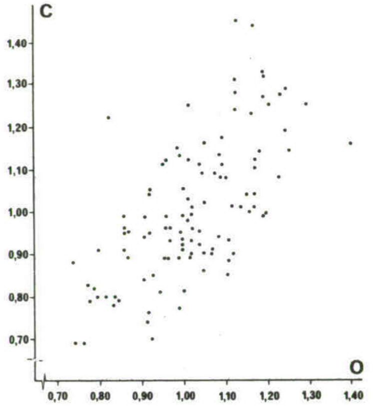


Figure 2: Plot of the cost-index (C) and the inputindex (I)

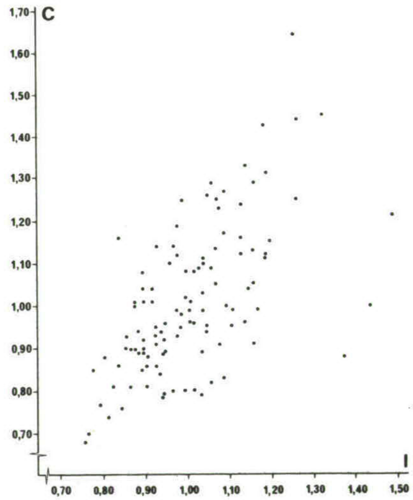
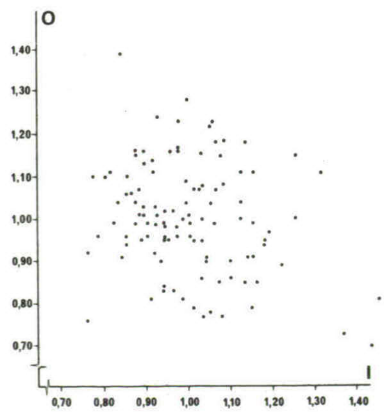


Figure 3: Plot of the outputindex of weighted admissions (O) and the inputindex (I)



In this components, factors such as the price differences of the allocated inputs, the greater or lesser efficiency with respect to the allocation of those inputs not incorporated into the production process like economic administrative staff, domestic staff and domestic costs, will play a role. The correlation between C and O is -.61 and that between C and I equals -.56. The correlation between O and I is much lower, namely -.20. In figures 1, 2 and 3 these relationships are represented graphically.
Feldstein states that the output index is particularly related to medical policy as carried out by the medical specialists. The input index I is related more to the policy of hospital management in the strict sense. The lack of a strong correlation between O and I is, according to Feldstein, related to the fact that medical policy and hospital management in the strict sense are independent of each other. From the correlation between I and O (-.20) it appears that these two indices for the behaviour of the decision-makers concerned are also weakly related. This means that hospitals with a high productivity can also have either a high or a low input efficiency. In other words, attaining a high productivity (a high output on the basis of the available levels of relevant inputs) does not depend on a high input efficiency.
We wonder, however, if such a strict separation between medical policy and not strictly medical policy can be made. There will be a certain interrelation between these two decision-making processes which will nevertheless be conducted by different people.
For even if the medical specialist is the one to take medical decisions, he will be led by the possibilities available within the hospital. In other words, his decisions will be influenced by the institutional setting within which he functions. Conversely, the hospital management will be influenced in their decisions by the medical specialists. Berki (1972) shares this opinion as well. It may be concluded from the above that the production function makes it possible to bring further nuances into the cost position, as can be calculated on the basis of the cost function. This can be an important supplement within the framework of interhospital. comparison ("mirror function", van Mansvelt (1979)). That is, an inter-hospital comparison that does not have to be limited to only a cost comparison, but in which the use of the inputs and the functioning of the hospital may be included as well.

To end this extensive introduction and summary, we will make a few more comments regarding the results of the cost functions in relation to the results based on the production function. From the cost functions it is apparent that the cost increase in hospitals (excluding specialists' fees). is only to a limited degree dependent on the production size, but is determined more by the development of the input prices and by the development of capacities. The differences in the utilization of capacities have for the total costs -at least within the range examined- a limited significance.

The production function provides insight into the utilization of inputs and into the different input combinations for a certain output. From the results it appears that there are between hospitals -keeping in mind the multi-product character- great differences in the utilization of inputs. The cost consequences of these differences (excluding specialists' fees) are small. But when, on the basis of insights obtained from the production function, it is possible to obtain a more efficient utilization whereby a reduction in capacity is possible, cost consequences as can be deduced from the cost function are, of course, to be expected.
In this connection we would like to quote Groot (1972):
If the capacity of the hospital has been made too big, then the chance of waste is quite large, and it is not so important whether or not all the empty beds are filled. Conversely, a hospital that is of a tighter capacity leads to lower costs, while the limited capacity causes the medical staff to make the effort to obtain the highest possible results with the given inputs. Stolte (1973) speaks in this connection of a "scarcity model".

Chapter II: Production functions, model specification and some considerations of the literature

In this chapter we will examine several model specifications (II.1). At the same time we will deal with some studies in the literature concerned with the application of production functions to the hospital sector (II.2).

II.1. Model specification[1)]

We will deal successively with a trio of production functions:
a) the Cobb-Douglas production function,
b) the CES production function,
c) the translog production function.

a) The Cobb-Douglas production function

Many applications of production function theory take as a starting point the Cobb-Douglas production function, in which simplicity is combined with a number of pleasant theoretical properties.
Starting with one output and p input factors the Cobb-Douglas production function has the following form:

$$Q = A.\prod_{i=1}^{p} X_i^{\alpha_i}$$

where: Q = output
A = constant
$X_1,\ldots\ldots.X_p$ = inputs
α_i = output elasticity of input factor i.

This production function specification implies that the elasticities of substitution between the inputs are all equal to 1 and are independent of the input levels. This last also goes for the output elasticities of the inputs.
The output elasticity of input j $\left(\frac{\partial Q}{\partial X_j} \cdot \frac{X_j}{Q}\right)$ can be derived as follows:

$$\frac{\partial Q}{\partial X_j} = \alpha_j.A.X_j^{\alpha_j-1}.\prod_{\substack{i=1\\ i\neq j}}^{p} X_i^{\alpha_i}$$

$$\frac{\partial Q}{\partial X_j}.\frac{X_j}{Q} = \alpha_j.A.X_j^{\alpha_j-1}\prod_{\substack{i=1\\ i\neq j}}^{p} X_i^{\alpha_i} . \frac{X_j}{A.\prod_{i=1}^{p} X_i^{\alpha_i}} = \alpha_j$$

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1) These considerations are based on Walters (1963), Cramer (1971) and Wallis (1973).

The output elasticities are constant and independent of the input levels.
The elasticity of substitution between e.g. X_j and X_k (e_{jk}) is defined as follows:

$$e_{jk} = \frac{\partial\ (\log X_j/X_k)}{\partial\ (\log R_{jk})}$$

R_{jk} is the marginal rate of substitution of input j for input k and is equal to the ratio of the marginal products of X_j and X_k. Here, the levels of the other inputs and of the output are held constant.
We then get for the Cobb-Douglas function:

$$R_{jk} = \frac{\partial Q}{\partial X_k} \Big/ \frac{\partial Q}{\partial X_j} = \frac{\alpha_k}{\alpha_j} \cdot \frac{X_j}{X_k}$$

$$\log R_{jk} = \log \frac{\alpha_k}{\alpha_j} + \log \frac{X_j}{X_k}$$

Thus: $$e_{jk} = \frac{\partial \log (X_j/X_k)}{\partial \log R_{jk}} = 1$$

The Cobb-Douglas function is homogenous to the degree:

$$(\alpha_1 + \alpha_2 + .. + \alpha_p) = \sum_{i=1}^{p} \alpha_i$$

This can be mathematically demonstrated as follows:

$$F\ (\lambda X_1, \ldots, \lambda X_p) = A\ (\lambda X_1)^{\alpha_1} \ldots .\ (\lambda X_p)^{\alpha_p}$$

$$= \lambda^{\Sigma \alpha_i} . A . \prod_{i=1}^{p} X_i^{\alpha_i} = \lambda^{\Sigma \alpha_i} . Q$$

If $\Sigma\alpha_i = 1$, then the output increases by λ% as the inputs are raised by λ%.
Economies of scale appear with $\sum_{i=1}^{p} \alpha_i > 1$ and diseconomies of scale with $\sum_{i=1}^{p} \alpha_i < 1$.

Thus, with the Cobb-Douglas function, scale effects are independent of the output levels and the input levels. These are stringent assumptions and the question is, what reality content they have.

Is it, in the framework of the hospital, realistic to assume that the elasticity of substitution, between, for example, the number of beds and the number of specialists is the same as that between the number of beds and the number of staff? Or that the substitution between, for example, the number of beds and the number of specialists is independent of the level of the inputs?
One can assume for oneself that the further the substitution between these two inputs has taken place, the more difficult it will be to make further substitutions.
One may also ask oneself if the output still increases with the same percentage (constant scale effects).

b) *CES-production function (Constant Elasticity of Substitution)*

Less stringent assumptions are made with the CES-production function. The model specification, with p inputs, is as follows:

$$Q = \left(\sum_{i=1}^{p} \theta_i X_i^{-\rho} \right)^{-\nu/\rho}$$

Where: e = elasticity of substitution[1)] $= \frac{1}{1+\rho}$

ν = degree of homogeneity.

With these specifications, the elasticity of substitution (e) takes on an arbitrary value; e is indeed constant and mutually equal for all inputs. Indeed, from the derivation of e_{jk}, it appears that it is not independent of the input levels.

1) The derivation of the elasticity of substitution between X_j and X_k using the CES-function is as follows:

$$\frac{\partial Q}{\partial X_j} = \frac{-\nu}{\rho} \left[\sum_{i=1}^{p} \theta_i X_i^{-\rho} \right]^{(-\nu/\rho)-1} \cdot \theta_j \cdot (-\rho) \cdot X_j^{-\rho-1}$$

$$= \nu \cdot \theta_j \cdot \frac{1}{X_j^{1+\rho}} \cdot Q^{1+(\rho/\nu)}$$

$$\frac{\partial Q}{\partial X_k} = \nu \cdot \theta_k \cdot \frac{1}{X_k^{1+\rho}} \cdot Q^{1+(\rho/\nu)}$$

$$R_{jk} = \frac{\partial Q}{\partial X_k} \Big/ \frac{\partial Q}{\partial X_j} = \frac{\theta_k}{\theta_j} \cdot \left(\frac{X_j}{X_k} \right)^{1+\rho}$$

Then: $\log R_{jk} = \log \frac{\theta_k}{\theta_j} + (1+\rho) \cdot \log \left(\frac{X_j}{X_k} \right)$

$$e_{jk} = \frac{\partial \log (X_j/X_k)}{\partial \log R_{jk}} = \frac{1}{1+\rho}$$

If we raise all inputs by λ, we get:

$$\lambda \left[\sum_{i=1}^{p} \theta_i \, (\lambda X_i)^{-\rho} \right]^{-\nu/\rho} = \lambda \left[\sum_{i=1}^{p} \theta_i X_i^{-\rho} \right]^{-\nu/\rho} . \lambda^{\nu} = \lambda^{\nu} . Q.$$

Thus the output increases by λ^{ν} if the inputs increase by λ. This implies that the scale effects are independent of the input levels.
If $\nu > 1$, we may speak of economies of scale , and if $\nu < 1$, of diseconomies of scale.

c) Translog production function[1)]

The translog production function can be considered as the first and second order terms of a Taylor expansion of a general production function:

$$\ln Q = f\,(\ln X_1, \ln X_2, \ldots).$$

The translog function with p inputs has the following form:

$$\ln Q \approx a_o + \sum_{i=1}^{p} a_i \, . \, \ln X_i + \sum_{i \leq j}^{p} \beta_{ij} \ln X_i \, . \, \ln X_j;$$

An equivalent version is:

$$\ln Q \approx a_o + \sum_{i=1}^{p} a_i \, . \, \ln X_i + \sum_{i,j}^{p} \beta_{ij} \ln X_i \, . \, \ln X_j;$$

where:

$\beta_{ii} = b_{ii}, \forall\, i$

$\beta_{ji} = \beta_{ij} = \frac{1}{2} b_{ij}, \forall i < j.$

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1) The translog function was brought forward by, among others, Christensen, Jorgensen and Lau (1973), Berndt and Christensen (1973, 1974) and Sargan in Layard et al. (1971).

2) Kmenta (1967). Zuidema (1970) has also suggested approaches to a more general production function.

The higher order terms will not be taken further into consideration.
With the above specifications, the number of parameters to be estimated already increases quadratically[1] with the number of inputs.
The advantage of the translog function is that the elasticities of substitution between the inputs may all be different and dependent on the level of the inputs.
The output elasticity of input X_j ($= \alpha_j$) is[2]:

$$\alpha_j = \frac{\partial Q}{\partial X_j} \cdot \frac{X_j}{Q} = \frac{\partial \ln Q}{\partial \ln X_j} = a_j + 2b_{jj}\ln X_j + \sum_{\substack{i=1 \\ i \neq j}}^{p} b_{i\,j}\ln X_i$$

$$\alpha_j = a_j + 2\sum_{i=1}^{p} \beta_{ij} \ln X_i$$

This output elasticity is dependent on the input levels. The derivation of the elasticities of substitution between the inputs is more complex (Appendix II.1). For particular values of $X_1, \ldots, X_p$ the elasticity of substitution between inputs j and k is:

$$e_{jk} = \frac{(\alpha_j + \alpha_k)}{(\alpha_j + \alpha_k) - 2 \cdot \dfrac{b_{jj}\alpha_k^2 - b_{jk}\alpha_j\alpha_k + b_{kk}\alpha_j^2}{\alpha_j \cdot \alpha_k}}$$

Here α_j and α_k are the output elasticities of, respectively, inputs j and k with the value $X_1, \ldots, X_p$ of the inputs b_{jj}, b_{jk} and b_{kk} are the concerned parameters from the translog model.
This definition implies that the elasticities of substitution between the inputs do not necessarily have to be equal to each other and may take on arbitrary values. Above all, they are dependent on the input levels.
In the Cobb-Douglas specification, b_{jj}, b_{kk} and b_{jk} are equal to 0 ; e_{jk} is then equal to 1, which is assumed in this specification.

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1) The number of parameters to be estimated (excluding the constant term) is: p (p + 3) / 2 (p = number of inputs).

2) In the terminology of Zuidema (1971) these are partial output elasticities. The general output elasticity is the sum of the partial output elasticities and is thus equal to the scale effects.

II.2. Consideration on the literature

Applications of production functions to the area of health care are not yet very numerous. Some examples in the hospital sector are Feldstein (1967b), Dowling (1971 and 1971a), Fraser(1971), Baron (1973, 1974 and 1975), Hellinger (1975) and Lavers (1976). P. Feldstein (1968), although he has undertaken no empirical estimates of production functions, has nevertheless shown their relevance of the framework of planning and the utilization of the inputs.
Several production functions have also been drawn up for the services of doctors: Bailey (1970), Kimbell and Lorant (1973) and Reinhardt (1971, 1973, 1975).
To the usual problems in empirical studies of this type several more may be added for the area of health care, such as the definition of the "output". It concerns not only the heterogeneity of the output but, as well, that which must be considered as output. Berki (1972) and Griffith (1978) distinguish between given hospital services ("production") and the effect of these services on the health status of the patient ("outcome"). Given the fact that at the moment no adequate instruments are available for the measurement of "outcome", all studies take "production" as a starting point. Applied to the hospital situation, this means, for example, that the number of patients treated in a particular year is seen as a function of the number of doctors, nurses, other staff, beds, equipment and medicines. When one chooses a Cobb-Douglas production function, this connection can be rendered in symbols as follows:

$$Q_j = A . \prod_{i=1}^{p} X_{ij}^{\alpha_i} . \varepsilon_j$$

Where: Q_j = output of hospital j, e.g. number of admissions
X_{ij} = quantity of input category i in hospital j;
for example: X_{1j} = number of doctors in hospital j
X_{2j} = number of nurses in hospital j, and so forth
j = 1, ..., N; there are N hospitals
i = 1, ..., p; there are p input categories
A = a constant
ε_j = residual error for hospital j
α_i = output elasticity of input i.

For a general model it would be necessary to have at one's disposal, as well as the production function, input-determining relationships (object function) which explain the behaviour. One would have to make assumptions about the model specification (nature of the relevant variables and the relationship among them) as well as the stochastic properties of the relationships. Marschalk and Andrews (1944) demonstrated that a direct estimate of the production function can lead to estimation problems. If the inputs are determined simultaneously with the output by a profit-maximizing firm, then the estimators of the ordinary least-squares method are not unbiased.

Depending on the assumptions regarding determination of the inputs, an adequate estimation method will have to be selected. Cramer (1971) has also shown that production is least of all a process that, starting from some input factors, will in itself achieve the intended result. As far as the hospital sector is concerned, up until now few theories are available about the production functions to be applied, the behavioural relationships and the stochastic properties of the process. It is clear that some basic models from the econometric literature, namely the profit maximisation and the public utility concept, cannot be applied fruitfully to the hospital sector (Van Aert, 1977). The traditional conception in which the production function specifies the (maximum) output through a given quantity of inputs and a given technology, and by which the firm organizes the production process (ratio of input factors) in such a way that a maximum profit or minimal costs result, is clearly unsatisfactory. The notion of profit, at least in hospitals in the Netherlands, is excluded by definition.
Baron (1973) distuiguishes a triad of steps in the entire allocation process:

1) First of all one must determine which services will be rendered at which desired quality level;
2) Once this is determined, one can go on to estimate the quantity of the demand for these services;
3) Thereafter the concrete allocation of the inputs can be undertaken to realize this (estimated) demand.

If one estimates a production function on the basis of empirical data, these three steps are then already completed in an entirely efficient or an inefficient manner. Baron takes as his starting point that, in the third phase, the objective of the hospital will be costs minimalization.
The concept of the public utilities, however, is equally unsatisfactory (see also Culyer et al., 1976). Regarding the comparison with public utilities, Feldstein (1967b) noted for the British hospital situation that:

1) The output level is not exogenously determined. According to Feldstein the great regional differences in hospital admissions indicate that the idea of a given demand which a hospital must satisfy does not work. Feldstein says that supply determines a great part of demand;
2) The hospitals have a limited freedom in dealing with input levels. The number of beds in a hospital remains practically the same from year to year.
   Regarding the medical staff and the nursing staff there are national wage scales.

Van Aert (1977) concluded that in the literature criticizing the two basic models (namely, profit maximising or costs minimising and the concept of the public utilities) great handicaps are indicated for the hospital sector. The output level is not exogenous, but much more endogenous with regard to the inputs, while in the hospital the input factors are not endogenous to an important degree, as we shall soon see.

Davis (1972) has worked out five alternative hypotheses in regard to the objectives of nonprofit hospitals[1]), namely:

a) aim at meeting costs by revenues
b) aim for output maximization
c) aim for output and quality maximization
d) aim for utility maximization
e) aim for cash-flow maximization.

Davis has tried, with the aid of a number of numerical analyses, to verify these hypotheses. She concludes that: "Future empirical testing should be oriented toward differentiating between hypotheses with a view to finding a reasonable model of hospital behaviour upon which public policy decisions can be based".
Jacobs (1974) also holds that further investigation is still needed before more definite models about the objectives of nonprofit hospitals can be arrived at.
A complication in working out such objectives is the specific relation between hospital and specialist. Feldstein (1974) states that an important problem is lack of an unambigous objective common to all those working in the hospital ("The hospital is a multiheaded animal").
On the above grounds we can also support the conclusion of Van Aert (1977) that, to date, studies of the economic behaviour of hospitals have not resulted in the framing of a generally applicable and testable hospital model. In further illustration reference can also be made to the series of articles in the journal Medisch Contact (Koninklijke Maatschappij tot Bevordering der Geneeskunst, 1973). Uniform ideas and concrete elaborations concerning objectives in health care are almost unable to be distilled from them.
In Chapter III we describe in more detail the situation in the Netherlands.
In three investigations (Baron, Hellinger and Dowling) a fixed objective is the starting point in constructing cost and production functions for hospitals.
In several studies the concerned functions are estimated without explicit formulation of a firm's objective. The functions are estimated directly and separately. Such a production function, based on cross-section data, can do no more than attempt to set out the relationship between the output and the inputs as they are allocated. It is thus not a structural equation and so, this production function offers no insight into the why of the allocation process. All that one does is look into how an "average" was allocated in the past. We can say that such a production function is a rendering of the history of the ex ante functions in the course of time as well as the actual choices made out of these ex ante functions.

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1) From an analysis of several complexity characteristics and the case mix of treated patients, Bays (1977) concludes that in profit-making hospitals (which therefore indeed have a clear objective) there is a tendency towards specialization in the "most profitable types of patient care". By this is meant the treatment of that type of patient which delivers the highest margin of price over costs.

In light of the above Johansen (1972) noted that if one, with the aid of the least-squares method, fits a production function to cross-section data, this function has in principle a descriptive value.
Evans (1971) has also shown this.
If one wants to arrive at optimalization models then the objective must be made explicit and operationalized. It is clear that if one is to succeed at this , the value and significance of the models must be greatly increased.
With the empirical estimation of production functions we are faced with three problems:

1) The output definition:
   this must be set out in such a way that the multiproduct character of the hospital is rightly delineated;
2) The definition of the inputs:
   these must be measured in an adequate manner and aggregated in meaningful categories in the light of the availability of data;
3) Model specification:
   a mathematical model must be constructed. This requires the specification of the form of a production function and a set of assumptions concerning the manner by which the input quantities are determined.

With the help of these three core problems we will look at several studies in the literature.

Definition of the output

None of the investigators start out from the "outcome" of the supplied services through measurement of the output. The output has an intermediary character in all studies. Many authors (Feldstein, Lavers, Dowling, Fraser, among others) go out from the idea that the core of hospital output is the number and type of patients treated.
In itself, the number of patients treated is too heterogenous and thus a further specification must be made. Feldstein (1967b) goes out from the division to specialties. The treated patients are divided among nine groups of specialties. Feldstein himself, discerns that this approach is not complete. There are for instance quality differences among the hospitals. Groot (1969) wonders if one can satisfactorily characterize the hospital function by means of a division of patients to specialties. Like Feldstein, he is of the opinion that a possibly better approximation can be obtained with the help of the diagnosis for which the patient is admitted.

Another question is, how one must put the differentiation of patients by specialties into the production function? Feldstein has put the specialism fractions as explanatory variables in the model. He obtains better results with the specialty fractions, weighted with the related coefficients from the costs functions (weighted number of admissions). Lavers (1976) goes out simply from the number of admissions. In his case this is nevertheless possibly a reasonably homogenous unit because he uses only maternity hospitals in his analysis. Moreover, the inputs are related only to clinical departments.

Dowling (1971), in his linear programming model, goes out from the number of patients treated, divided into 55 diagnosis groups. Baron (1973) uses the number of patient days along with the number of admissions as his departure point. With admissions as well as with patient days an adjustment is made for outpatient activities in the light of the ratio of outpatient and inpatient revenues. Greenfield (1973) comes to the conclusion on the basis of the revenue ratio that 3 outpatient visits, and 4 emergency visits are equivalent to 1 patient-day.
In a publication of the American Hospital Association (1970) it is said that 4,9 outpatient visits are the equivalent of 1 patient-day.
Baron has an alternative for the "patient-day" unit. He says that the treatment of one patient requires one set of intermediary inputs such as, for example, patient-days, operations, laboratory tests, X-ray tests etc. Each of these intermediary outputs is weighted with the help of the revenues. Cohen (1970) has also used this output unit in his costs functions. Fraser (1971), in estimating production functions for Canadian hospitals, has used Cohen's notion in measuring the output. Hellinger (1975) takes as his starting point the number of patient days and aggregation of treatments carried out. Hellinger uses as weighting factors not the revenues but the average costs of the individual outputs in the 60 hospitals taken up in his analysis.
Seeing that quality is a very difficult factor to measure, it is not explicitly included in a single output specification.

Definition of the inputs

The theory of the production function requires that the inputs be specified in terms of physical magnitude.
The production function is, for all that, a technical relation between the output and the inputs. Sometimes, however, only monetary and not physical values are known.
Feldstein distinguished the following inputs: the number of beds, the salary costs of the nursing staff, the salary costs of the medical specialists and the costs of various other goods and services such as drugs and dressings
With regard to the nursing staff (Feldstein, 1967b) notes that the Cobb-Douglas or Leontief functions are not feasible when different types of staff are taken up in the model. However, output will not, as is implicitly assumed in these production functions, require a positive quantity of each of the inputs. It is correct that, none of the inputs in in this production function are equal to 0, as Feldstein points out. However, in a double logarithmic equation the original variable may not take on the value of 0. Reference can be made in this connection to Reinhardt (1971) and Mitry et al. (1976) who, because of this problem, chose for a specific form of the translog production function. To tackle this problem Feldstein proposes to aggregate the staff categories with the aid of the salaries. An additional advantage is the fact that the salaries are based on national scales, but information is of course lost through this aggregation.

Baron (1973) uses the prices of the inputs and the output level to estimate the cost function and derived the production function from it, because of the assumed duality. Baron distinguishes 6 inputs: 5 inputs related to the labour factor and 1 input (namely, the number of beds) related to the capital factor. Other inputs are not included in this consideration.
Hellinger (1975) considers the inputs in physical as well as in monetary terms. The labour factor is measured via the total labour costs or through the number of staff members. In regard to this distinction, he notes that if the salary of a particular employee represents his labor productivity, total labour costs will be a better measure for the labour input than the number of employees. The number of beds is utilized as an index for the amount of capital. Hellinger also estimated a model in which depreciations are included as the unit of measure for the amount of capital. This leads to less valuable results than the number of beds. This is related to the fact of differences among hospitals in depreciation methodology.
Other goods and services are included in the production function only in monetary terms.
Hellinger concludes that ultimately the following input measure gives the best results: the labour factor via the labour costs, the number of beds as an approximation for the stock of capital and the costs of the remaining goods and services as a third input factor.
Lavers (1976) goes out from the number of beds, the costs of nursing, the costs of specialists and the costs of other goods and services. He is of the opinion that starting from from physical magnitudes would be better. Several uninterpretable results are brought about, according to Lavers, through going out from monetary magnitudes.
Not all inputs are included in the production function in some investigations (Lavers, Feldstein, Baron, Fraser). One can ask oneself whether, starting from the concept of a production function (i.e. given a technical relationship between the output and the inputs), all input must be included. Feldstein poses himself the question of whether, for example, the costs of nursing and domestic costs must be included in a production function. He assumes that in a more general production model the output is not influenced by the nursing and domestic costs, within the observed range. Something similar can certainly be assumed with regard to the categories Lavers omitted, for example, costs for food, energy costs, and so forth. Yet Lavers (1976) has also cited a number of other reasons for not including the mentioned inputs in the production function. They form a very small fraction of the total costs, have a great variance and demonstrate high correlations with other inputs that are indeed included.

Model specification

When the output and inputs have been defined, one must subsequently choose a mathematical model of the production function.

The choice of the model depends on the objective of a hospital and the manner in which the allocation process is used to reach this objective. It is also important for the model specification what is assumed about the possibilities of substitution between inputs, the output elasticities and the scale effects. We have already pointed out the as yet unsatisfactorily worked out nature of the theory about the objectives of a hospital. In the most empirical studies with respect to cost and/or production functions of hospitals, so-called behavioural functions are estimated.
Three of the above-mentioned investigations do indeed start from a determined objective and subsequently construct and estimate a model. Baron (1973) starts from cost minimization and formulates a cost function based on a Cobb-Douglas specification. Hellinger (1975) assumes that hospitals strive for maximization of their stock of capital goods (facilities) and the greatest possible margin between total revenues and current costs. By current costs is meant here total costs excluding depreciations. This hypothesis is the same as that brought forward by Karen Davis (1970). Davis assumed, namely, that hospitals try to maximize their cash-flow in order to bring about a continuing expansion of facilities. Davis defines cash-flow as the net revenue (= total revenues minus current costs) + depreciations.
Cash-flow is then, according to Davis, the increase in monetary resources for new investments. These monetary resources are not accumulated but are rather invested in construction and equipment.
Hellinger, in contrast to Davis, assumes that to a great extent hospitals borrow money for the financing of new investment goods. Hellinger states as a factual conclusion that somewhat more than 60% of the investments are financed with borrowed money and thus not with internal funds.
Hellinger formulates an utility function which is maximized starting from a certain specification of the production function. The utility is seen as a function of the capital goods stock and profits (in the sense of net revenue). Based on empirical testing of the production model, Hellinger concludes that this concept better suits the data than the pure profits-maximizing conception.
Newhouse (1970) concluded that this model is not satisfactorily directed to the special characteristics of the hospital. He has not reckoned with the fact that diverse groups work in a hospital, each with its own objectives. Newhouse characterizes Hellinger's model as an "organism hospital", while a model in which the accent is more on the individuals in a hospital working to reach their goals is regarded as an "exchange" model. Feldstein (1974) has also pointed this out. Moreover, with the Hellinger model, one must be mindful that, along with the assumptions about the objectives and the specification of the utility function, rather stringent assumptions must be made with relation to marginal productivity conditions. Regarding the form of the production functions, Hellinger has tested a great number of specifications:

the Cobb-Douglas, CES, Uzawa, Sato and translog specifications. He concludes that the translog model gives good results. The Cobb-Douglas and CES specifications have, according to Hellinger, several properties that are too restrictive. Dowling (1971) takes as starting point in his approach that hospitals strive for a maximum output. He defines output as the number of treated patients divided into 55 diagnosis categories. Feldstein (1967b), Lavers (1976) and Fraser (1971) do not formulate an explicit objective and estimate the production function directly. No input-determining equations are taken up. To that end, the stochastic assumption is made that the error term in the production model is independent of the inputs.
Such an assumption becomes justified, according to Feldstein (1967b) if the inputs are determied through central government regulations, local supply conditions and past decisions. Seeing the structure of the British hospital sector, Feldstein considers this a meaningful and feasible beginning hypothesis. Often regarding the production function for specialists only a direct estimate of this function is made (Reinhardt 1971, 1975; Kimbell and Lorant 1973; Bailey 1970). In another publication Reinhardt (1973) goes further in formulating the objective and the possibly related question of the simultaneous bias in a direct estimate of the production function. Under certain assumptions the simultaneous bias is slight (Hoch, 1958). Considering the above, it appears meaningful at this point to estimate the production function directly. In interpreting the results, however, one must indeed take a possible simultaneous bias into account. Feldstein concludes that, as far as the form of the production function goes, the Cobb-Douglas production function is very satisfactory for general hospitals in England. Lavers finds the best results for maternity hospitals with a translog specification. Fraser uses a Cobb-Douglas production function for general hospital estimates. Baron (1975) makes the distinction between a treatment function and a production function. The treatment function is related to the allocation of treatments and patient-days for a certain number of patients. The production function concerns the relationship between this intermediary production (treatments and patient-days) and the inputs (labour, capital etc.).
To conclude the problems concerning model specification, we must still go a bit further into the question of methodology. The foregoing dealt mainly with continuous production on the basis of statistical data from a number of hospitals (cross-section analysis). Several authors (Berki 1972; Dowling 1972 and Reinhardt 1973) have also brought forward another means of approximation, namely, activity analysis. This approach does not start from one aggregated production function, but rather from a number of production processes (activities) which take place in the hospital. Dowling has carried out an analysis for one hospital. He has drawn up a linear programming model whose object function is the number of treated patients divided into 55 diagnosis categories.

This object function is maximized by starting from, on the one hand, technical production data for the treatment of a particular diagnosis category and, on the other hand, from maximum capacities that are imposed upon the production possibilities. The technical production data concern, for example, the number of "necessary" patient-days, laboratory tests, X-ray tests etc., for a patient from one of the 55 diagnosis categories which are distinguished. The maximum capacities, concern e.g. the maximum possible number of laboratory tests and the maximum number of patient days which can be "produced". With the aid of such a model, one can obtain more insight into the production processes in a hospital. Thus it becomes possible to see where certain bottlenecks may appear in the production process; for example, is laboratory capacity statisfactory for a given supply of patients? One can also compare real production with "optimum" production. More insight is obtained into the relationship between the testing and treatment of a particular patient and the total infrastructure of a particular hospital. One is referred in this connection to Groot (1976, 1978).
Along with Dowling, Reinhardt (1973) has also shown the possibilities of activity analysis. As already said, the separate production processes can be seen in such a model conception (see also Brown, 1970). Bailey (1970) has proposed estimating "continuous production functions" for these production processes. Reder (1970) considers Bailey's approximation method inadequate. He holds that the separate production processes are not considered separately at the aggregated level. Verheyen (1975) has proposed an alternative for the micro-approximation of Dowling and Reinhardt. Based on the "input-output" theory model, he develops a theoretical model for analyzing in a particular hospital the relationships between central and supporting departments and the ultimate costs-bearer (the patient).

In our investigation we are focussing on the estimation of production functions for the hospital in its totality on the basis of cross-section data. In the next chapter we describe the allocation process in the Dutch hospital sector, we define the output and the inputs and the model specification.

Chapter III: Problems in constructing and estimation of production functions for hospitals in the Netherlands

This chapter deals with the application of production function theory to the Netherlands' hospital sector. Here the core problems, as has already been said, are measurement of the output and the inputs and the specification of the relationship between the inputs and the output. These must be approached via the real hospital production process. In III.1 a description is given of the production structure of the general hospitals. III.2 concerns the measurement of the output and the inputs and the model specification. In III.3 the available data are described.

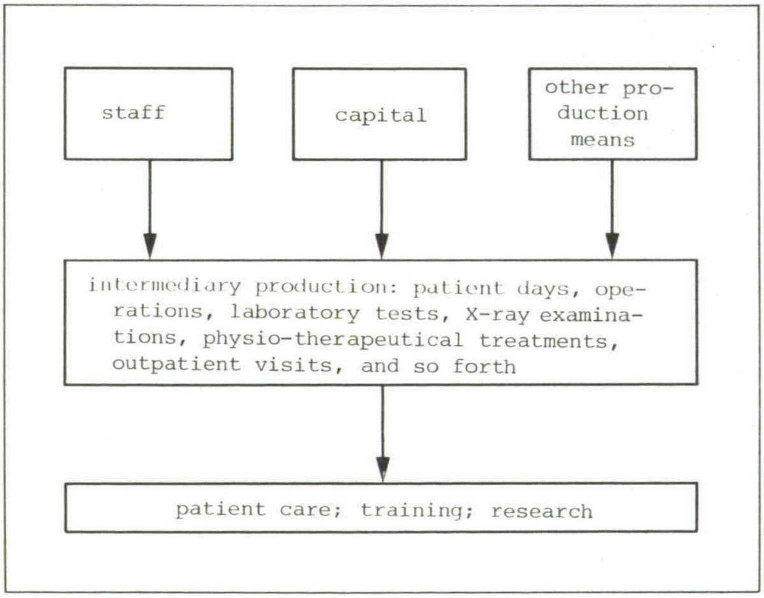
III.1. Description of the production structure of general hospitals

a. "Outcome" versus production

In economic theory the final output is that which statisfies the need of the consumer (Berki, 1972). From this, one mostly goes on to say that in itself the consumption of certain goods and/or services will lead directly to optimal satisfaction of needs. The consumer will choose the goods and/or services himself on the basis of his scheme of preferences. With regard to health care it is difficult for the consumer (patient) to judge what he needs to improve his health situation ("consumer ignorance"). Clearly the patient is less interested in the number of patient days or the number of operations or drugs provided him, than in the chance that they lead to better health. This implies that the consumer (= patient) does not "buy" from the hospital, for example, 16 patient days, 1 operation, drugs, and so forth but rather the expectation that his level of health will improve. The patient will therefore be rather indifferent with respect to the combination of (medical) services or to any of their components. The patient eagerly wants to be quickly and completely cured.
The specialist gives concrete form to this demand in terms of the use of the inputs ("agent-supplier relation") (see also Feldstein, 1977).
The final output of a hospital can now be defined as the contribution the hospital's activities make to bettering the patient's health situation. Chen et al. (1975) and Griffith (1978) hold that one should be obliged to measure the effect of the rendered care on the health level of the patient (effect measurement).
In this connection Timmer et al (1975) have introduced the notion of health benefits. Van Aert (1978) notes that until now only poor progress has been made in evaluating the influence of health care on the health situation (see also Ament, 1979). The "outcome" of the rendered care is not known.

In such an evaluation of the outcome, one can not limit one-self to hospital activities but must also consider extra-murally rendered health care (e.g. general practitioners) as well as care in other intramural health care institutions (e.g. nursing homes, psychiatric institutions).
However desirable such an approach may be, realizing it is nevertheless difficult and remains as yet only theoretically possible. Thus, one can not use a final output approximation as a starting point.
As already concluded above, in the investigations under study, the concerned applications of production function theory to the hospital sector is not chosen for the final output approximation ("outcome"); one goes out instead from the care rendered ("production").
Groot (1978) says that one should see hospital production as an intermediary production of hospitals and specialists together, a production that on balance must be of service to the welfare of the patient. Output is also measured in our study by means of the "production" of the care rendered. We shall throw some light on this approach with the help of the diagram below (see also Van Aert, 1977).

Scheme. Hospital model



A hospital treats patients (inpatient/outpatient) and provides for particular training and research functions (III); (on this see, among others, "Rapport Werkgroep Van Leeuwen" Ministerie van Volksgezondheid en Milieuhygiëne, 1974,; Van Nieuwenhuizen, 1971; Ruchlin and Leveson, 1977). For the execution of these functions "intermediary production" takes place for example, patient-days, laboratory tests, operations, X-ray tests, physiotherapeutic treatments, outpatient visits, and so forth (II). In this diagram the production is central, not the effect ("outcome") of production. For this production inputs (labour, capital, other goods and services, are available (I). With regard to the patient treatment, the hospital is not only concerned with creating the conditions for a responsible patient care. Groot (1978) notes that the conviction is gaining ground that the hospital is developed from a working place for specialists into an institution in which everyone with his role try in cooperation with others to give the patient the best possible care. Patient care can be seen as the result of the combined effort of doctors and hospitals. Van Nieuwenhuizen (1971) states that to an increasing degree the specialist is becoming subordinate to the management and the board of a hospital has become more conscious of his role. He also points out the special role of biochemists, medical physicists, sociologists and psychologists in patient care. He speaks in this connection of the "dethroning of the physician" (Van Nieuwenhuizen, 1974 and 1978).

The necessity for the integration of specialists into hospital organization is pointed out in the report of the Werkgroep Van Leeuwen (Ministerie van Volksgezondheid en Milieuhygiëne, 1974b). Through the Dutch national union of specialists (Landelijke Specialisten Vereniging) and the hospital council (Nationale Ziekenhuisraad), a model of a contract between hospitals and specialists has been drawn up as well as model rules for the medical staff (Landelijke Specialisten Vereniging, 1977). Therein are set down the mutual rights and duties of both hospital and specialists. The starting point is the joint task to render optimal care to the patient. Treatment is undertaken by the specialist under his personal responsibility. Rogiers (1979) is of the opinion that, through the development of different specialized disciplines (technicians, paramedical staff) and the functionalizing of the hospital medical care (the tasks of the specialist are seen more and more as function of the hospital), hospital medical care are now irreversibly taken up wholly within the hospital.

The hospital, along with its patient care function, also has a training and research function. The training function is marked off into different components: specialist training, clerkship training, nursing aide training, nursing training and several specific trainings such as for example, medical analyst, radiological assistant, dietician and children's nurse.

The composition of the training programme shows great differences among hospitals. Some training programmes (e.g. nursing training) are at present in virtually all general hospitals, others in only a few.

In 1971 nearly 30% of the general hospitals had a specialist training programme and nearly 40% has clerkship training. Also, 30% had a training programme for nursing aides. Van Aert and Van Montfort (1978a en 1978b) go further into the meaning of the content of training programmes as well as the requirements these programmes make on institutions.
Little is known about research activities in the hospital, especially medical research. This aspect will not be explicitly dealt with any further in our considerations.

b. Quality of hospital care

The quality as well as the quantity of hospital care must be a part of output measurement. From the work of Stolte (1977) and Van Maanen (1978) it can be concluded that a concrete measuring instrument is lacking for both medical and nursing activities. A number of principles have been formulated, though there is no consensus about them; an operational instrument is not yet on hand. Longest (1978), in a study of the relationships between quality and (direct) costs, for a number of hospital departments, has distinguished three aspects of the quality of care. These are the structure, the process and the "outcome" or the result of the system. The structure and organization are measured via the quality of the training of medical specialists (percentage of Board-certified specialists). For an evaluation of the process, physicians and nurses from the hospitals and outside experts ("Experimental Medical Care Review Organization in Georgia") were asked their opinion. The rank order of inside and outside experts is virtually identical.
"Outcome" was measured with the aid of an "adjusted" mortality-index from the hospitals. Roemer, Moustafa and Hopkins (1968) have developed this index, taking account of the differences among hospitals in type of patients ("case severity").
The correlations between the different measuring points can be said to be very high. Consequently Longest has set up a relationship between the quality aspects measured in this manner and the (direct) costs. He concludes that the relations are significantly negative. This implies, according to Longest, that higher (direct) costs do not lead to higher quality; rather, in fact, there is evidence of the opposite. Crucial to this analysis, of course, is to what degree the quality measurements Longest employs are realistic. Berry (1974) and Neuhauser and Turcotte (1972) approach quality via the "accreditation status" of the hospital and the presence of particular facilities. Accreditation status is based on a test of a number of (minimum) standards which, among other things, are related to the completeness of medical dossiers, the organization of medical staff and the adequateness of physical facilities. The authors conclude that there is a positive relation between costs, size, training programmes status and the thus-measured quality.
Morse et al. (1974) have constructed a scale index for the extent that new technologies are applied in hospitals. This index is based on "expert opinion", relating to a particular lung disease, which is seen as representative for the entire hospital.

Shortell et al. (1975) have defined as approximations of quality several variables relating mortality for internal medicine and surgery to postoperative complications. They conclude that there is the suggestion that higher costs are associated with poorer, not better, quality of care.
Hegyvary et al. (1976a and b) have executed several empirical studies concerned with the delivering of nursing care in hospitals. They stress the process of nursing care delivering and not the "outcome" and the organizational structure of the care-delivering system. As the investigators remark, much more work is necessary before the quality of the rendering of nursing care can be quantified.

It can be concluded from the above that the operationalisation of the quality of health care is not yet possible. Ae will not consider this aspect explicitly in our investigation. However, in the considered variables, it may be implicitly taken up certain quality components.

c. *The allocation process in the general hospital*

Insight into the allocation process is needed before one is able to start drawing up production functions. For production, inputs will be required. For this, a distinction must be made in the planning of capacities and infrastructure (long term) and allocation in the framework of the running costs of an institution (short term). For planning, (re-)allocation will be able to be related to most or all inputs. For a given hospital in a certain year, allocation will have a much slighter flexibility. When one is going to build a new hospital the possibilities, for example, of minimizing the hotel function and making more use of the day care function, are much greater than when a hospital building already exists.

The Dutch Ministry of Health and Environmental Hygiene and the Council for Hospital Facilities have drawn up a number of rules and guidelines with regard to the planning of the capacities and other infrastructural provisions in intramural health care. In the framework of our analysis present capacities and infrastructural provisions are a datum in which littel is to be changed in the course of the analysis period (of one year).
The Central Board for Hospital Tariffs (COZ) works according to a cost and tariff policy regarding the operation of hospitals. The individual hospital draws up an estimation of the costs based on the preceding year and a projection about developments in the coming year. These are tested in the light of a number of norms and guidelines[1]. The norms and guidelines are especially concerned with staff and depreciations and interest. Staff depends on the (estimated) size of production.

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1) For more information about the COZ, see Centraal Orgaan Ziekenhuistarieven, 1978.

Salary levels for private institutions are determined by a collective labour agreement (CAO voor het Ziekenhuiswezen; see NZR, 1978). In public institutions these are determined by the government. In general, salaries in private institutions follow the trends in the public institutions. The CAO does take up a number of specific elements especially fringe benefits[1].
For the price development of the material costs, COZ contributes a certain percentage, based on macro-economic developments such as those forecast by the Central Planning Bureau (Centraal Planbureau).
Depreciations, in line with a linear depreciation scheme, are based on the historical price of the assets. For buildings, the annual depreciation is 2%, for installations 5%, and for equipment 10%.
Interest which may be calculated as a part of the costs is equal to the interest paid on loans given to finance hospital investments. Calculating interest on own funds is not allowed. An extra depreciation of ƒ 0,50 per patient day (renovation fund) is allowed for hospitals built before 1949. COZ policy is meant to reimburse hospitals for real costs in so far as these costs can stand up under a reasonable critical test. The position of the hospital as to what is reasonable is evaluated with regard to a system of norms and guidelines, developed over the course of time and regularly adjusted, as well as in the light of price increases of the inputs as changes in the delivered medical services (Groot, 1975; Wagner, 1975).

The norms and guidelines do not concern the number of tests, examinations and treatments. Thus there are, for example, guidelines relating to staff in the laboratory, but no norms relating to size and nature of the laboratory production. The costs of drugs are taken up into hospital costs. One can state that COZ does not busy itself with the number of tests, examinations and treatment of the patients. The setting of norms is restricted ultimately to the conditions in which investigation and treatment of the patients take place (Groot, 1974). Thus COZ, with the evaluation of a hospital's cost position, goes out from the array of services it delivered. This implies that the size of a hospital and its infrastructure are accepted as a datum. Staff, given the occupancy of beds and the treatment departments, is tied to certain COZ guidelines. With decreasing use of beds and guidelines, with regard to nursing staff, are flexibly applied in order to prevent hospitals from getting ever increasing cost deficits, this because staff is not directly adjustable to a changing utilization. Guidelines concerning the norms for the nursing staff were recently laid down (COZ-Vademecum, 1978).

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1) Just as is concluded in a joint report of the Dutch National Hospital Council and the Ministry (Nationale Ziekenhuisraad, 1975) there indeed are differences in level of (net) salaries between the two categories of hospitals.

On the basis of the available data, we can only pursue what is allocated ex post. Throug a comparison of the budget estimate (ex ante) and the realization (ex post), more insight can be obtained into possible adjustments during the year. This will be initiated in particular through anticipation on possible costs deficits or surplusses on account of deviations of (anticipated) realizations in the course of the year regarding the budget estimate. If one want to get more insight in the dynamics of the allocation process than it is required to construct a dynamic model, based on the developments in time. In our investigation we limit ourself to a cross-section analysis.

From the allocation process described above, one can conclude that the inputs will have a very inflexible character on short-term and in each case will be much more dependent on the expected output than on the observed output. That the inputs will only slightly depend on the observed output level also appears from the low marginal costs in terms of the average costs (Van Aert, 1977).
It appears from many studies that the supply of hospital provisions determines the (realized) demand to a great extent. The demand-supply mechanism will have the result that the output of a hospital is to a great extent determined through the inputs than otherwise. Factors, possibly connected with this demand-supply relationship are the conscious elimination of the price mechanism for the consumer through the (social) insurance system as well as through the finances and fees systems. In the health care delivering system, moreover, there is also talk of a specific relationship between consumer (patient) and producer (specialist); Berki (1972) characterisizes this as an "agent-supplier" relationship.

III.2. Definition of output and inputs; model specification

Measuring the output

In line with the above description (scheme page 60), the output is approached via two lines:
a) in terms of patient care and training programmes (weighted admissions; weighted patient days)
b) in terms of patient days, operations, laboratory tests, X-ray tests, outpatient visits etc. (intermediary production).

Ad a.

As said above, different elements of the hospital function are distinguished. Unless one includes the multiproduct character of the hospital in drawing up the production function errors will appear in the estimates. This can be done in different ways.
Klein (1953) draws up the different elements of the output as explanatory variables in the production function. One can also raise the different output elements to one denominator so that one output measure is obtained.

In many studies quantification of patient care goes out from the number of admissions (or the number of patient days). This is a heterogenous quantity. Thus, with regard to the diagnoses and specialisms of the admitted patients, great differences appear among hospitals (NZI, 1975 ; Van Nieuwenhuizen, 1976).
One must thus introduce a differentiation, of which the starting point is the utilization of the inputs ("iso-resource"-patient groups; Lave and Lave, 1971).
To weigh the differentiation in patient care on uses the coefficients of the specific variables in the costs per admission model (Van Aert, 1977). These are the degree of despecialization[1] (the extent in which patients are admitted into the subspecialisms of internal medicine and surgery with regard to the basic specialisms of internal medicine and surgery), the percentage of ENT patients and the outpatient variable (percentage of revenues) from total hospital treatment which belongs to outpatient treatments.
The training function is applied in the output in relation to presence or not of specialist training and the matching coefficient from the costs model.
It is assumed that, via costs ratios like those brought forward from cost functions, the heterogeneity of the number of admissions with relation to the allocation of inputs is taken into account in a satisfactory way[2].

The definition of the weighted admissions of hospital i is as follows:

$$WADM_i = [2987{,}54 + 0{,}196.Dsgr_i^2 - 33{,}847\ Dsgr_i + \\ + 207{,}29\ Spec.tr_i + 1{,}759\ Outp_i - 18{,}133\ ENT_i]\,Adm_i/1598{,}60$$

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1) It is possible that a better classification of patients can be drawn up with the aid of diagnosis data. At the moment, however, these data are known for only a small number of hospitals. Different studies shows that such data have good possibilities (Evans and Walker, 1972; Rafferty, 1972; Luke, 1979; Goodisman and Trompeter, 1979).

2) M.S. Feldstein (1976b) assumes that admissions which are relatively more costly have, to the same degree, a greater social utility or they contribute also to the same degree to satisfaction of needs.
In this way the problem that an actual price for health care on the output market does not exist, is hedged.

Where: $WADM_i$ = weighted admissions of hospital i in a year

Adm_i = number of admissions in hospital i in a year

$Dsgr_i$ = degree of despecialization of hospital i (the measure of the extent of specialization in internal medicine and surgical specialisms)

$Spec.tr_i$ = presence of specialist training in hospital i (yes = 2; no = 1)

$Outp._i$ = outpatient variable of hospital i (the outpatient revenues of the treatment department as a percentage of total treatment department revenues of hospital i).

ENT_i = % of ENT patients. (Ear-, nose- and throat-specialism).

The constant term 2987,54 is determined in such a way that the average costs per admission (1598,60) go up through filling in the values of the variables for the average hospital. Owing to this, WADM for the average hospital is equal to the number of admissions. This implies that the weighing mechanism leads to a relating of the number of admissions with regard to the average number.
The calculations in table 6 illustrate the weighing mechanism.

Table 6: Calculation of weighted admissions for several hospitals.

	average hosp. 1	hosp. 2	hosp. 3	hosp. 4	hosp. 5
ADM	6962	6962	6962	6962	6962
Degr. of despecialization	82,88	82,88	$\boxed{50,00}$	82,88	82,88
Specialist training	1,30	1,30	1,30	$\boxed{1,00}$	$\boxed{2,00}$
Outpatient variable	32,44	32,44	32,44	32,44	32,44
% ENT patients	14,15	$\boxed{20,00}$	14,15	14,15	14,15
WADM	6962	6500	8079	6691	7594

Hospital 1 is the average hospital. We see that the weighted admissions ($WADM_i$) is equal to the number of admissions (ADM_i) In hospital 2 the percentage of ENT patients is notably higher (20%) than in the average hospital (14,15%). In this case the number of weighted admissions falls off notably (6962 versus 6500). This is because the ENT patients have a lower weighing factor than the average admission. In hospital 3 we see the reverse: if we set the degree of despecialization at 50, which assumes more "complicated" patients, then the number of weighted admissions increases sharply, namely from 6962 to 8079. Comparison of hospitals 4 and 5 gives some insight into the influence of specialist training on the number of weighted admissions. Hospital 4 offers no training (factor 1,00), which leads to a weighted number of admissions to the amount of 6691. Hospital 5 does offer specialist training (factor 2) and the number of weighted admissions is notably higher, namely 7594.

The outpatient variable appears less revelant for hospital costs. It therefore has little influence on weighted admissions. This influence could increase in the future, however, when the shift from inpatient to outpatient rendering of health care actually occurs.
An error in the output definition can be connected with the interrelationships of the weighing coefficients. From many kinds of tests with cost functions, no indications are obtained of disequilibriums in the interrelationships between the cost coefficients (Van Aert, 1977).

Some authors choose to got out from the patient day (weighted patient days) as central output unit rather than from admission (weighted admissions). The patient day is one of the central items in the COZ policy (Poels, 1979). It is taken up in our investigation as an alternative.
The formula for weighted patient days is as follows:

$$WPAT_i = [178,30 + 0,00997\ Dsgr_i^2 - 1,739\ Dsgr_i + 0,019\ Outp._i + - 0,23\ ENT_i + 13,114\ Spec.tr._i]\ PD_i/96,97$$

Where: $WPAT_i$ = number of weighted patient days for hospital i in a year
PD_i = number of patient days for hospital i in a year.

The coefficients are the estimated parameters from the model of costs per patient day (Van Aert, 1977). The constant terms in the formula are chosen in such a way that one get the number of patient days by filling in the variables for the average hospital.

Ad b.

Intermediary production is understood to be the sum of patient days and treatments. "Intermediary" must be seen in relation to patient care. The "treated patient" himself is, again, also intermediary with regard to "outcome".
There is a great diversity in the kinds of treatments.
These are all brought to one denominator on the basis of the rates charged for them. These tariffs are uniform for all Dutch hospitals. According to COZ, treatment tariffs are a representation of the variable costs and an additional charge for the direct fixed costs of a particular treatment . The difference in treatment tariffs (for hospitals and not for specialists) for sick fund patients with respect to private plays only a slight role or no role at all.
The same goes for rates for inpatient in respect of outpatient treatments. Revenues from drugs are considered entirely as inpatient revenues. This can be problematic for some hospitals if the supplying of drugs lies completely outside the bookkeeping of the hospital. This last goes in a very few cases for some treatments (e.g. laboratory).
The outpatient factor is included via revenues per outpatient hour.

In most cases the specialist pays the hospital an amount per sitting hour for use of the outpatient space[1].
For the patient day tariff one goes out from the national average rate.
A complication there is that in some hospitals not all treatments are declared seperately (all-in/all-out difference (Groot, 1960)). To that end, the "all-in" part is eliminated from the patient day tariff of a hospital. This "all-in" part, represents the revenues from the "all-in" treatments when these are to be separately declared. This goes only for inpatient treatments. The outpatient treatments are always declared "out". Relating to the "all-in" part, distinctions are made between "1st and 2nd class" and 3rd class patient days. Patient days for healthy infants are left out of this consideration. With a "physician-in" tariff the "all-in" parts also contain a subpart relating to the specialist's fee. Inasmuch as this does not come up often in general hospitals, it will only lead to a slight deviation. The same is assumed with regard to differences between the gross and net revenue arrangement in X-ray-related treatments.
In 1971 65% of revenues from inpatient treatments were declared separately.

Both output definitions have a two fold character. The weighted admissions (resp. the weighted patient days), as defined under Ad a, are cost-oriented through the weighing coefficients. However, the output unit of a particular hospital is not total costs but rather a weighted total admissions. It is an index which, with relation to the different types and numbers of treated patients as well as training functions, represents the position of a particular hospital relative to other hospitals. In Chapter I we went into the question of whether this output definition leads to tautological statements. The intermediary production, as given under Ad b, is tariff oriented. However, the intermediary production of a hospital is not equal to the total revenues of that hospital but rather represents its position in terms of patient days, treatments and so forth, relative to other hospitals.

Measurement of the inputs

One can devide the inputs into three categories:
a) capital
b) labour
c) other goods and services
The measurement of these categories is gone into below.

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1) This arrangement was modified after the appearance of a report about the outpatient function of hospitals (Nationale Ziekenhuisraad et al., 1975).

a. The factor capital

- the number of beds:
  the number of beds is an important input factor to which a great part of hospital activities, particularly in nursing care, are related.
- the facility index:
  the facility index is a quantification for the infrastructure of a hospital. In Van Aert c.s., 1976b it is said that a bed in a small hospital (e.g. with 200 beds) is something different from a bed in a (e.g. 700 bed) hospital. There is a great difference in the facilities "around the bed".
  The facility index is seen as an approximation for these qualitative differences. The facility index is a proxy variable for the diversity in the infrastructure at hand and gives a specification of the hospital function. This index will not only directly connect with investments but -possibly still more important- with costs of staff and the costs of other goods and services. Regarding staff, one think of paramedical staff especially and of nursing staff in lesser degree.
  In the light of investments, we can get an indication of expansion in the infrastructure. In the course of time the share of investments in medical inventories, to which category investments in facilities belongs to a great degree, increases sharply. In the period 1968 through 1976, the annual increase in total investments in the average hospital was 9,9%; in the same period this percentage for investments in medical inventories amounted to 18,8% (Van Montfort et al. 1979).

One can see beds and facilities as an approximation for the amount of capital. Taken up in this form, one can get around differences in historical purchase prices of the assets.

b. The factor labour

- staff:
  In defining staff, the starting point is the relevance for the production process, and thus the output. Civil, domestic and economic-administrative services (411)[1] are supported and have no direct relevance for the production process. However, an increase, for example in domestic staff, will not generally lead to an increase of the output.
  These inputs have more of a complementary character and will be left out of further considerations.
  The staff relevant for the production function is still rather heterogenous.

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1) The numbers between brackets, here and below, refer to the relating numbers from the NZI-Rekeningschema (1968) (Accountingscheme).

It seems meaningful to make the following distinctions:
a. registered nurses (412)
b. student nurses (413)
c. other nursing staff (414)
d. paramedical staff (415).
We start from the average staff per category in a certain year. This is calculated on the basis of the 12-months averages, whereby part-timers are converted into full-time staff.
The percentage share of the different staff categories in 1971 was as follows:
general staff (411): 33,5%
registered nurses (412): 19,0%
student nurses (413): 22,9%
other nursing staff (414): 7,8%
paramedical staff (415): 12,4%

- number of specialists:
Although most medical specialists are not on the pay-roll of a hospital, the number of specialists is an important input factor in the treatment of patients. Here, one can make a distinction between attending specialists and supporting specialists. Attending specialists are directly concerned with the examination and treatment of patient (e.g. internal disease specialist, surgeon) while the supporting specialist (e.g. clinical chemist, pharmacist) have an indirect task. For 1971, the only known data is about the number of specialists that did have or did not have a full-time job in a hospital. For 1972 and later years additional data is known about the conversion form part-time to full-time basis.
In our analysis no distinction is made about whether or not specialists are salaried by the hospital. As was already noted above, in 1971 the number of salaried specialists in general hospitals was still slight. On the basis of staff statistics, one can conclude that in 1971 there were 500 specialists on the pay-roll in general hospitals. This number increased in 1978 to nearly 800. This is about 15% of the total number of specialists working in all hospitals (Poeisz, 1978).

c. *Other goods and services*

- drugs and dressings (461 and 462) and other medical and paramedical means (471 and 472):
These two input factors are known only in monetary units. It seems reasonable to assume that there will be no great differences between hospitals regarding prices paid for them. In 1971, the costs of drugs and dressings, etc. amounted to 9,7% of total costs.

Inputs are defined and measured above. One input is lacking, namely the "manager" capacities and expertise of the executive staff and other decision-making personnel, e.g. the medical staff. In a hospital the ultimate decision regarding the diagnosis and therapy of the patient is taken by the attending specialist.

Although the number of specialists is taken up in the production function, their decision-making conduct and the differences therein are not[1].
Attempts are made by some investigators to measure efficiency more directly, e.g. via the occupancy rate and length of stay. Pulley and Fulmer (1975) additionally see the debtor's balance, among other things, as a measure of the managerial efficiency of a hospital. In the light of a hospital's financing and tariff structure, this seems to us a much too limited approach, and we will return to this topic in Chapter V.

Model specification

Single equation model

Seeing the difficulty in operationalizing the objective of a hospital, a descriptive production model is drawn up that gives some insight into the how of allocation and not into the why. Such a production function gives no insight into the output and the allocation of the inputs in function of the objects of a hospital and, moreover, considering the output measurement, it certainly gives no insight into the final output or the outcome of medical activities. Such a production function does tell us which input combinations occur in actuality for a particular production.The production function is quantified by relating the differences among hospitals in the output to the differences in the inputs.
In practice, we see differences in the input at a given output and different outputs at given inputs. These relationships can be described with the aid of production functions. We will have to make assumptions about allocation behaviour and about a number of characteristics of the production structure. An important question is whether the input levels in a certain year are dependent on the output level or whether, on the contrary, the output (in the short term) is dependent on the inputs (simultaneous equation bias). As already said, it seems reasonable to assume that different inputs, in the short term, are fixed. For example, the number of beds and the infrastructure are difficult to adjust or are not adjustable in the short term, to a decreasing output. The same can be said in regard to the labour factor (staff and specialists).
COZ policy implies that the input levels will be dependent on the expected output to a greater extent than on the realized output. An exception must possibly be made for drugs. These are more readily fitted to a changing output level.

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1) Walters (1963) poses that one can interpret the error term in a cross-section model as an approximation for the difference of the behaviour of the decision-makers. Walters notes that the error term in a time-series model can have a different meaning than in a cross-section model. For example, with a production function for agriculture, the weather in one year can be different than in another, while in the cross-section approach it is constant.

From estimates of a model in which this aspect is reckoned with, it can be concluded that this does not lead, however, to other results than in the model in which it is not reckoned with (Appendix III.1). It is said along with this that indications emerge from different studies that the realized demand depends to a great extent on supply.
Hoch (1958, 1962) shows that if the current decisions have a lot more to do with an anticipated or estimated output, then the real inputs have no relation to the error term in the production function; thus there will be no burden of simultaneous bias. From the procedure described for allocation in the hospital sector, it can be concluded that these assumptions are fulfilled. In Chapter I we went into the duality theory concerning the relationship between cost and production functions. It was concluded that the direct estimation of the production function is permitted. Reinhardt (1975) says that although his single equation estimates will not be free of a bias, these disturbances will not be serious In this connection he cites Griliches, Konijn and Walters. They are of the opinion that one can accept single equation estimates of the production function if one does realize that the estimates will be liable to a few biases. In this connection Walters (1963) notes that -given the alternatives that one has as an investigator- it "is dangerous to be pedantic about the superiority of the simultaneous equations over single equation methods" in estimating production functions. One of course obtains more information and insight if one can estimate the production function as a part of a more complete production decision model with an object function, input-determining restrictions, sales equations, and so forth. If one has only a slight or no insight into the specifications of this model, and in addition, no adequate data available, one has the chance of introducing even greater biases in estimating the production function in a simultaneous equation system than one goes out form single equation estimates (see also Reinhardt, 1975; Layard et al., 1971).

Structure of the equation

Consequently assumptions must be made about the production structure, that is to say, the form of the relations between the output and the inputs. Model choice must take place on this basis. Are the output elasticities of the inputs dependent on the input levels? Is, for example, the increase in output which results from an increase in the number of staff members dependent on the level of the number of staff members? It seems acceptable that, with an increasing increment in the number of staff members in proportion to the other inputs, the increase in the output will decrease. We shall illustrated this. Say we have two inputs: 100 staff members and 100 beds. If, with this given number of beds, we raise the number of staff members form 100 to 110, the output will increase with a higher percentage than if the number of staff members is raised from 110 to 121.
Another characteristic of the production structure is the elasticity of substitution, that is to say, the degree to which one input is substitutable for another.

Are the substitution possiblities between staff and beds equal to those between staff and specialists?
Is the elasticity of substitution between staff and beds independent of the input levels or is it becoming more diffucult to substitute one input for another?
With the issue of elasticities of substitution, we must note that responsibility for medical care is primarily a matter of the medical specialists. What matters is whether we can observe in practice whether there are input combinations with relatively more or fewer specialists in relation, for example, to the number of nurses.
The scale effects are also an important problem. Scale effects concern the extent to which the output increases with a certain increase of all inputs. Are these dependent on the output level or are they depend on the input levels? The latter implies that the scale effects are for example, different in "big" hospitals and "small" hospitals. In Chapter I a number of assumptions are described in further detail. Seeing beforehand that little clarity exists about the production structure, different models are tested.
In this regard, then our investigation has an especially exploratory character.

III.3. Data; description of the sample

In the above the output and the inputs are defined and the model assumptions are given. For output measurement, two ways are distinguished, namely, on the basis of weighted admissions (respectively the weighted patient days) and on the basis of intermediary production.
The inputs are divided into three groups, namely, capital (beds and facility index), labour (staff, specialists) and other goods and services (drugs etc.).
The model estimates are based on a 1971 cross-section analysis. The necessary data are known for 110 general hospitals. The academic and specialised hospitals are left out of consideration because of the homogeneity assumptions. In academic hospitals, with respect to general hospitals, the education and research factor plays a very specific role, along with advanced medical care. Here the demarcation between hospital and medical faculties is not yet clear. From financial and staffing statistics of academic hospitals and general hospitals, it appears that the average costs per patient day (*f* 663,94 resp. *f* 282,40) and the average staff per 100 beds (309,3 resp. 152,6) is notably higher in academic hospitals than in general hospitals (NZI 1979, nr. 79.165; NZI 1979, nr. 79.179). With regard to the specialised hospitals, it must be noted that patient care is limited to one or a few specialisms.
In table 7 some statistical data are taken up relating to the output and the inputs, as defined above. Also in the table the data are split up into the four function groups. General hospitals are classified into four function groups, based on the composition of the medical staff.

Table 7: Some statistical data of the output and the inputs of general hospitals per function group (1971).

Variables	totality		function group I		function group II		function group III		function group IV	
	average	coeff. of var.	average	coeff. of var.	average	coeff. of var.	average	coeff. of var.	average	coeff. of var.
Output										
1. Number of admissions	6.968	0,49	3.935	0,47	5.567	0,36	7.782	0,36	11.829	0,28
2. Weighted admissions	7.431	0,59	3.748	0,51	5.446	0,37	8.405	0,42	14.321	0,31
3. Number of patient days	114.867	0,51	61.000	0,46	87.598	0,34	130.687	0,36	205.200	0,26
4. Weighted patient days	126.989	0,55	62.949	0,49	91.076	0,37	143.262	0,42	247.702	0,29
5. Intermediary production	11.993.400	0,59	5.287.398	0,43	8.914.375	0,39	13.373.725	0,38	24.183.293	0,31
Inputs										
6. Registered nursing staff	95,97	0,66	40,47	0,51	64,94	0,43	103,87	0,52	180,96	0,31
7. Student nursing staff	127,16	0,54	63,00	0,63	97,13	0,44	145,35	0,40	212,50	0,24
8. Other nursing staff	19,39	1,08	12,59	0,72	15,06	0,95	15,83	0,72	49,01	0,74
9. Paramedical staff	59,24	0,83	21,18	0,70	38,03	0,49	63,02	0,57	140,21	0,40
10. Total (6 through 9)	293,48	0,61	137,18	0,57	215,36	0,39	328,25	0,43	584,85	0,26
11. Beds	336,81	0,51	183,00	0,38	264,14	0,34	389,00	0,35	615,64	0,26
12. Facility index	8,02	0,53	4,18	0,70	7,03	0,46	9,65	0,37	15,00	0,19
13. Specialists	28,12	0,47	16,41	0,45	21,33	0,32	31,63	0,23	49,93	0,28
14. Drugs	1.203.400,08	0,90	465.721,96	0,98	888.813,60	0,83	1.262.417,65	0,57	2.739.467,09	0,57
N (number of hospitals)	107		17		36		40		14	

From function group I to function group IV, the composition of the staff is always more extensive (Van Aert and Van Montfort, 1976).
In function group IV the average number of admissions per hospital is 11.829; in function group I it is 3.935. This is 3,0 times as much and is tied up in great part with the number of beds.
In function group IV the average number of weighted admissions is 14.321; in function group I it is 3.748. This is 3,8 times as much. From this it can be deduced that the admissions in function group IV hospitals ara "more difficult" than those in hospitals in function group I. The difference is about 25% (3,8/3,0 = 1,27). From the BKZ report, part 2 (NZI, 1975) it appears that the less frequently occuring diagnoses occur more often in the hospitals of function group IV than they do in hospitals of function group I.
The expected lenght of stay is longer in function group IV hospitals than in hospitals of function group I. We see the same tendency relating to the number of treatments per 100 admissions (see also Chapter V). Regarding patient days, we see the same tedency as with admissions. In function group IV the average number of patient days is 3,4 times as high as in function group I and the number of weighted patient days is 3.9 times as high. The average intermediary production per hospital is notably higher in function group IV (4,6 times) than in function group I. This is linked in great part with the difference in average size of the hospitals in the different function groups. Relating intermediary production to the number of admissions avails more insight here.
The ratio between intermediary production and the number of admissions is 2.045 for function group IV and 1.344 for function group I. This means that on the average a higher intermediary production takes place for the admissions in function group IV hospitals (nearly 1,5 times as much) than for the admissions in function group I. As said above, the less frequently occuring "relatively complicated" illnesses are, relatively speaking, more strongly represented in function group IV than in function group I. For the "relatively complicated" patients in function group IV, the intermediary production per admission is higher than in function group I.
If we relate the intermediary production to the weighted admissions, the differences betwen the function groups is notably smaller. Therefore this points to systematic patterns between the intermediary production (patient days, treatments and so forth) and the type of admission and the training function. In the second part of table 7, the inputs are shown. From group I to group IV they increase. The variation coefficients of virtually all variables are lowest in function group IV. This is related, among other things, to the smaller variation in the number of beds in group IV.
With the aid of the production function, it is possible to quantify the systematic relationships between the output and the inputs.

Chapter IV: Estimation of production functions for general hospitals

In this chapter a number of production functions will be estimated. This concerns alternatives with relation to the outputs, the inputs and the model specification. We will deal successively with Cobb-Douglas functions (IV.1), CES functions (IV.2) and translog functions (IV.3). As was said in Chapter II, the Cobb-Douglas specification is a submodel of the translog function. Thus, with the help of nested tests on the translog specification, we can test whether more specific forms (e.g. the Cobb-Douglas specification) are valid (Draper and Smith, 1966). These tests are undertaken in IV.3. However, because of the explorative character of our study and because the Cobb-Douglas specification is applied in different foreign studies, we will first deal separately with this specification. One can approximate the CES specification with a model nested in the translog specification, but one then gets non linear relations between the coefficients. This model can not be efficiently estimated with the aid of the ordinary least-squares method (see also Bridge, 1971).

IV.1. Estimation of Cobb-Douglas production functions

In Chapter III we gave a few output definitions, namely: weighted admissions (respectively weighted patient days) and intermediary production.
For weighted admissions (respectively weighted patient days), different quantifications are possible. One can put the different elements of this output definition as explanatory variables in the model to be estimated.[1]
Following Feldstein (1967b), one can put the elements directly in the output with the help of weighing factors. Feldstein takes as weighing factors the related parameters from the cost function.
This weighing procedure was described in Chapter III. In Appendix IV.1, different alternative quantification possibilities are compared with each other. It can be concluded that, of the alternatives, the weighted admissions is the most satisfactory. This output measure gives a good fit of the models to the data, the estimated parameters are generally easy to interpret and the number of parameters to be estimated is much smaller than in the first alternative.
Table 8 shows the estimation results of the Cobb-Douglas specification for weighted admissions, weighted patient days and intermediary production and 5 inputs.

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[1] Klein (1953) has also applied such a procedure in a production function for railway services.

Table 8. Results regression analysis of Cobb-Douglas specification (ln - ln specification) for weighted admissions, weighted patient days and intermediary production with 5 inputs.

Inputs	weighted admissions $\hat{\beta}$	$\hat{\sigma}_{\hat{\beta}}$	weighted patient days $\hat{\beta}$	$\hat{\sigma}_{\hat{\beta}}$	intermediary production $\hat{\beta}$	$\hat{\sigma}_{\hat{\beta}}$
Constant term	9,81	0,36	5,13	0,15	9,22	0,17
Staff	0,32**	0,11	0,22**	0,06	0,26**	0,06
Beds	0,67**	0,12	0,90**	0,06	0,66**	0,06
Drugs	0,050*	0,038	0,011	0,012	0,12**	0,02
Specialists	0,028	0,063	0,007	0,034	-0,025	0,031
Facility index	-0,038	0,036	-0,042**	0,019	0,026*	0,018
R^2	0,94		0,98		0,99	
N	107		107		104	
$\bar{R}^2$	0,94[1)]		0,98		0,99	

* $2\hat{\sigma}_{\hat{\beta}} > |\hat{\beta}| > 1{,}645\hat{\sigma}_{\hat{\beta}}$; significant at 10% level

** $|\beta| > 2\hat{\sigma}_{\hat{\beta}}$; significant at 5% level

The functions are estimated in a double logarithmic specification and an additive error term with the aid of the ordinary least-squares method (Van Gelderen 1975; Johnston 1963). It is assumed that the error terms are independent of each other and normally distributed, with expected value 0 and constant variance.
The R^2 of the three models are high. For the weighted admissions the R^2 is a bit lower than for the weighted patient days (0,98) and the intermediary production (0,99). The R^2 concerns the explanation of the differences in the ln (output) and not to the differences in the output. In the concerned models, the R^2-s are comparable with those in several foreign studies (Feldstein 1967b; Lavers 1976; Fraser 1971; Baron 1973; Hellinger 1975).
The parameter estimates in the three models exhibit differences at several points. With the Cobb-Douglas function the output elasticities are equal to the parameters and thus can be read directly from Table 8.
The estimates of the coefficients of the number of beds are 0,67 (σ = 0,12) for weighted admissions, 0,90 (σ = 0,06) for weighted patient-days, and 0,66 (σ = 0,06) for intermediary production.

1) $\bar{R}^2 = 1 - (1 - R^2)\,\frac{N-1}{N-k-1}$; N = number of hospitals;
k = number of variables excl. constant term.

The number of beds is thus an extremely relevant factor for the differences in the output. The meaning of the number of beds for the weighted patient days is significantly higher than for the weighted admissions and the intermediary production. This difference is linked with the differences in conception of the outputs. In the weighted admissions and the intermediary production, certain aspects play to a greater extent a role which is less directly related to beds than in the weighted patient days. The number of admissions is less strongly determined by the number of beds than the number of patient days. This can be illustrated in the light of the much greater coefficient of variation in the turnover rate (15,0%) than in the occupancy rate (6,2%). The turnover rate is the number of admissions per bed per year (NZI 1974).
With a view to the intermediary production it can be noted that the number of treatments is less strongly bound to the number of beds than is the number of patient days. The occupancy rate and the % of revenues from treatments in the intermediary production are hardly linked at all ($\rho = 0,04$).
Difference is also to be noted in the parameters of the (nursing and paramedical) staff. The staff occupancy is more relevant for the weighted admissions (0,32;σ = 0,11) than for the patient days (0,22;σ = 0,06) and the intermediary production (0,26;σ = 0,06). The staff has thus a greater impact on admissions than on the patient days and the production of medical treatments.
The output elasticity of drugs for the intermediary production is 0,12 (σ = 0,02). There can be talk here of tautology. In the intermediary production, the revenues of drugs and dressings are taken up. The input "drugs" is equal to the costs of drugs and dressings. The difference between the revenues and the costs of drugs and dressings is a certain incremental percentage. On this, one may refer further to Appendix III.1 where several models are estimated in which drugs are assumed to be endogenous with regard to output resp. to the other inputs.
The other inputs are barely or not at all significant. An exception is the facility index for the weighted patient days. Although the influence is slight, it is quite significantly negative. The question is to what extent this result depends on the model specification. With the translog specification, the parameter of the facility index is not significantly negative (IV.3). With the other output definitions, the facility index has no significant influence.
Van der Gaag et al. (1975) have estimated a Cobb-Douglas specification with as output the number of patient days and as inputs the number of beds, the number of nurses, and the number of specialists. The parameter estimates of these 3 inputs are nearly the same as our estimates.
Feldstein (1967b) gets an output elasticity of ± 0,50 for the number of beds with relation to the weighted admissions and one of 0,40 for the salaries of the medical staff. The nursing and paramedical staff are barely relevant.
Lavers (1976) gets less easily interpreted results also working with the Cobb-Douglas specification. The output elasticity of the number of beds is 0,25 and seems rather low. Lavers gets better results with the translog specification.

The medical staff has, in contrast to Feldstein's results, a barely significant influence; we see the reverse with regard to nursing staff.
This difference possibly involves the fact that Laver's study has to do with maternity hospitals and Feldstein's with general hospitals.
Baron (1973) concludes, on the contrary, that nursing services are the most relevant input factor while the number of beds is scarcely relevant (for either adjusted admissions of intermediary output). This can indicate that the dual approximation of the production function indeed leads to results difficult to interpret. However, the result with regard to the number of beds is hard to accept. Hellinger (1975) gives little or no interpretation of his results in terms of the output elasticities. His study is more directed to testing some alternative hypotheses about behaviour. The estimates allow us to see that the most relevant input factor is the number of beds. The results from these studies are not always the same.
This can be connected with the different production structures in the different countries treated, but also with differences in the definition of the output and the inputs as well as the assumptions made about the model (see also Chapter II).
The number of specialists has no significant influence on the output. This appears to conflict with our hypothesis that a greater number of specialists will lead to a greater number of weighted admissions. In the above models the starting point is the number of specialists working in a hospital. No reckoning is taken here with whether the specialists in a given hospital work full-time or not.
The conversion for the number of specialists working full-time is known for a small number of hospitals. These data are given in Appendix IV.2. In the smaller hospitals the specialists work part-time to a greater degree. In the hospitals with less than 150 beds the ratio between the number of working specialists and the number of specialists reckoned via the full-time conversion is 1,80. In the hospitals with more than 600 beds this factor is 1,06. These differences are stronger for supporting specialities (e.g. clinical chemistry, bacteriology, radiology, etc.) than for attending specialities, directly related to patient treatment. The figure for those working part-time in a hospital is greater for sub- and superspecialities than for the basic specialities (see also Van Montfort et al. 1979). In Appendix IV.2, several production functions are estimated with the number of specialists converted to a full-time basis. In this case there is indeed a significant influence on the weighted admissions. The coefficient of the number of (conversion-determined) specialists for the weighted admissions is 0,27 (σ = 0,09). This implies that an increase of 1% in the number of full-time (conversion-determined) specialists leads to an increase in the output (weighted admissions) of 0,27%. The difference in the specialists directly concerned with diagnosis and treatment ("attending specialists") and specialists with a supporting function in these respects ("supporting specialists") is also not without significance.
The elasticity of the attending specialists is somewhat higher than that of the supporting specialists.

The coefficients of the other inputs remain virtually unaltered by the conversion to full-time basis. One can not generalize these results, because the number of hospitals for which this data is available is small and possibly not representative for all hospitals. On the basis of the estimated parameters one can obtain insight into the scale effects. The sum of the parameters for the weighred admissions is 1,03 with a standard deviation of 0,05; for the weighted patient days it is 1,09 with a standard deviation of 0,03 and for the intermediary production 1,04 with a standard deviation of 0,03.
This implies that, starting from the Cobb-Douglas specification, there are no significantly advantageous or disadvantegeous scale effects in relation to the weighted admission. Significantly advantageous scale effects are to be found with respect to the weigthed patient days. If all inputs increase by 1%, we estimate that weighted patient days increase by 1,09%. These advantageous scale effects may be related to the number of patient days (occupancy rate) and to the type of patient day (weighing elements). The scale effects with respect to the intermediary production are smaller than with respect to the weighted patient days. Feldstein (1967b) concludes that to a smaller extent one may speak of disadvantageous scale effects ($\Sigma\alpha_i = 0{,}97$; $\sigma = 0{,}03$). The scale effects in bigger hospitals are somewhat less disadvantageous than in smaller hospitals. Lavers (1976) finds disadvantageous scale effects, Fraser (1972) advantageous. Baron (1973) finds advantageous scale effects for the different output units. This also holds for his production function study concerning the obstetric and gynaecology department (Baron, 1977).
In the models treated above, the staff is taken up in totality. Table 9 gives the Cobb-Douglas estimates for the three output definitions; here, several inputs are taken up in more differentiated form. The R^2-s of these models are alsmost equal to those of the less differentiated models.
The input "drugs" is not included in this model, in order to compare it with the more differentiated translog specification in which drugs is also not included. This is especially because of the great number of parameters there would then be to estimate. We see in these models the different effects of the separate staff categories.
The most relevant staff category for weighted admissions is the registered nursing staff, while student and other nursing staff are the most important staff categories for weighted patient days. These differences are considered further in IV.3.
Paramedical staff is the most important staff category for the intermediary production; registered nursing staff comes next.

Table 9: Results regression analysis Cobb-Douglas production function (ln - ln specification) for the weighted admissions, the weighted patient days and the intermediary production with 7 inputs.

Inputs	weighted admission $\hat{\beta}$	$\hat{\sigma}_{\hat{\beta}}$	weighted patient days $\hat{\beta}$	$\hat{\sigma}_{\hat{\beta}}$	intermediary production $\hat{\beta}$	$\hat{\sigma}_{\hat{\beta}}$
Constant term	10,89**	0,34	16,17	0,01	10,60	0,20
Reg. nursing staff	0,22	0,08	0,02	0,05	0,10**	0,05
Student nursing staff	-0,04	0,03	0,03*	0,02	0,015	0,019
Other nursing staff	-0,006	0,02	0,02*	0,01	-0,0065	0,012
Paramedical staff	0,10**	0,04	0,07	0,07	0,131**	0,027
Beds	0,69**	0,12	0,98**	0,07	0,78**	0,07
Facility index	-0,007	0,04	-0,03*	0,02	-0,0004	0,027
Specialists	0,05	0,06	0,02	0,03	0,043	0,037
R^2	0,94		0,98		0,99	
N	107		107		104	
$\bar{R}^2$	0,93		0,98		0,98	

* 2 $\hat{\sigma}$ $|\hat{\beta}|$ > 1,645; significant at 10% level.

** $|\hat{\beta}|$ > 2σ; significant at 5% level.

IV.2. Estimation of CES production functions

IV.2.1. Introduction

The Cobb-Douglas model is, when certain assumptions about the error term are made, an easy to estimate model.
Through a double logarithmic transformation we obtain a function which is lineair in the parameters. We get the necessary estimates through the application of the ordinary least-squares method. Such a rather simple transformation is not possible with the CES production function. (Chapter II).
For the estimation problem different approaches are to be found in the literature. Arrow et al. (1961) assume that the homogeneity parameter (ν) is equal to 1. One then obtains the following model:

$$Q_j = \left(\sum_{i=1}^{p} \theta_i X_{ij}^{-\rho} \right)^{-1/\rho} \quad (j = 1 \ldots N)$$

The parameters of this more limited CES function can not be directly estimated with the aid of the ordinary least-squares method for linear models. It is not possible, unless ρ is known, to obtain a linear function in the parameters by means of a transformation.
Arrow et al. (1961) now pose that the elasticity of substitution
$e = \left(\frac{1}{1+\rho} \right)$ can be estimated from the added value per unit of labour and the price of labour (salaries). If the observations are generated through maximum-profit seeking firms with perfect competition in the market for the factor labour and the products, then the marginal product of labour is equal to the price of labour. If ρ is known, a lineair function arises in the parameters after transformation.
Feldstein (1967a) has investigated for the hospital sector the assumption which Arrow et al. use as a starting point. He says that the marginal productivity condition implies that the hospitals choose the inputs in such a way as to minimalize the total costs for a given output. The same can be said with regard to the scale effects assumed by Arrow et al. to be constant.
It can be assumed that the price of labour for the hospitals has an exogenous character. However, Feldstein notes that in general the hospitals are confronted with the same salaries (national scales). This also goes for the factor capital. This brings about an unsatisfactory variation in the input prices in a cross-section study.
Feldstein (1967a) concludes that the Arrow et al. estimation method rests on too many implausible assumptions to be applicable for the hospital sector. Therefore he proposes another procedure. Feldstein takes as his starting point different values of ρ (and thus also of the elasticity of substitution e) and ν (degree of homogeneity) and then estimates the parameters of the linear model (after transformation) with the least-squares method. In this way one obtains an estimate of

the production function parameters for each a priori value of ρ and ν taken up (step 1). Feldstein takes as his basis for selecting the "best" parameters the correlation between the observed values of the output (Q_i) and the predicted value:

$$\hat{Q}_i = \left\{ \widehat{Q_i^{-\rho/\nu}} \right\}^{-\nu/\rho}$$

Here, following Feldstein, it is noticed that the maximizing of the correlation (step 2) will not lead to the highest possible correlation between Q_i and $\hat{Q}_i$ because step 1 is directed toward explaining the differences in $Q_i^{-\rho/\nu}$ and not in Q_i. This two-step procedure of Feldstein will be applied in IV.2.2. IV.2.3. will deal with two alternatives for the estimation of the CES function, namely, a modified Feldstein method (IV.2.3.1) and a nonlinear regression analysis (IV.2.3.2).

IV.2.2. Estimation of CES production functions with the Feldstein method

Table 10 shows the results of the estimation of several production functions for the weighted admissions via the Feldstein method; it always starts form a certain ρ and a certain ν and then the ordinary least-squares method is applied. As criterion for choosing the "best" solution, Feldstein uses the highest correlation between the observed output and the predicted output. These correlations are nearly 0,96 for each model. This implies that the data according to Feldstein's criterion permit little differentiation between models. Feldstein suggests studying along with this the parameter estimates.
To this end, Table 11, going out from the average hospital, shows the output elasticities of the number of beds and the registered nursing staff.
From Table 11 it can be gathered that, taking the standard deviations into account, there are great differences in the output elasticities with the diverse combinations of ρ and ν.
It is striking that with a given ν the output elasticities do not vary strongly with ρ. This goes especially for the output elasticities of the number of beds. It does not go for the reverse.
$\nu = 1$ is seen to be the most acceptable output elasticity in the table. However, not acceptable are the significantly negative output elasticities of, for example, the number of beds, or elasticities that are notably greater than 1.
It can be concluded from the above that the Feldstein method does not lead to the choice of a model. We will therefore look at two alternative methods in the subsections below.

Table 10: Estimation results of the CES production function (Feldstein method).

Inputs	$\rho = 0,3$			
	$\nu = 0,5$	$\nu = 1,0$	$\nu = 1,5$	$\nu = 2,0$
Registered nurses	$0,252.10^{-3}$ $(0,061.10^{-3})$	$0,520.10^{-2}$ $(0,266.10^{-2})$	$-0,0121$ $(0,0118)$	$-0,0677$ $(0,0331)$
Student nurses	$-0,106.10^{-4}$ $(0,128.10^{-4})$	$-0,921.10^{-3}$ $(0,468.10^{-3})$	$-0,449.10^{-2}$ $(0,244.10^{-2})$	$-0,0101$ $(0,0069)$
Other nursing staff	$-0,651.10^{-5}$ $(0,791.10^{-5})$	$-0,128.10^{-3}$ $(0,291.10^{-3})$	$-0,514.10^{-3}$ $(0,151.10^{-2})$	$-0,0014$ $(0,0043)$
Paramedical staff	$0,504.10^{-4}$ $(0,304.10^{-4})$	$0,795.10^{-3}$ $(0,112.10^{-2})$	$-0,474.10^{-2}$ $(0,581.10^{-2})$	$-0,0202$ $(0,0163)$
Beds	$-0,535.10^{-5}$ $(0,116.10^{-3})$	$0,301.10^{-1}$ $(0,425.10^{-2})$	$0,201$ $(0,022)$	$0,507$ $(0,062)$
Specialists	$-0,135.10^{-3}$ $(0,312.10^{-4})$	$0,639.10^{-3}$ $(0,114.10^{-2})$	$0,0315$ $(0,0059)$	$0,0984$ $(0,0168)$
Drugs and dress.	$0,292.10^{-4}$ $(0,192.10^{-3})$	$-0,147.10^{-2}$ $(0,705.10^{-2})$	$-0,0213$ $(0,0368)$	$-0,065$ $(0,103)$
Other (para)med. means	$0,119.10^{-2}$ $(0,512.10^{-3})$	$0,428.10^{-1}$ $(0,188.10^{-1})$	$0,012$ $(0,097)$	$-0,211$ $(0,275)$
Fac. index	$0,205.10^{-4}$ $(0,107.10^{-4})$	$-0,277.10^{-4}$ $(0,392.10^{-3})$	$-0,337.10^{-2}$ $(0,204.10^{-2})$	$-0,0107$ $(0,0057)$
R^2	0,984	0,998	0,998	0,997
N	107	107	107	107
$\bar{R}^2$	0,983	0,998	0,998	0,997

Inputs	$\rho = 0,2$			
	$\nu = 0,5$	$\nu = 1,0$	$\nu = 1,5$	$\nu = 2,0$
Registered nurses	$0,385.10^{-2}$ $(0,984.10^{-3})$	$0,0162$ $(0,756.10^{-2})$	$-0,0247$ $(0,0232)$	$-0,102$ $(0,0496)$
Student nurses	$-0,176.10^{-3}$ $(0,250.10^{-3})$	$-0,347.10^{-2}$ $(0,192.10^{-2})$	$-0,0101$ $(0,589.10^{-2})$	$-0,0176$ $(0,0126)$
Other nursing staff	$-0,632.10^{-4}$ $(0,157.10^{-3})$	$-0,354.10^{-3}$ $(0,120.10^{-2})$	$-0,145.10^{-2}$ $(0,369.10^{-2})$	$-0,332.10^{-2}$ $(0,792.10^{-2})$
Paramedical staff	$0,996.10^{-3}$ $(0,520.10^{-3})$	$0,308.10^{-2}$ $(0,400.10^{-2})$	$-0,0117$ $(0,0123)$	$-0,0375$ $(0,0263)$
Beds	$-0,392.10^{-3}$ $(0,158.10^{-2})$	$0,0854$ $(0,0122)$	$0,343$ $(0,0373)$	$0,667$ $(0,0799)$
Specialists	$-0,228.10^{-2}$ $(0,534.10^{-3})$	$0,268.10^{-2}$ $(0,410.10^{-2})$	$0,0642$ $(0,0126)$	$0,157$ $(0,0270)$
Drugs and dress.	$0,658.10^{-3}$ $(0,136.10^{-2})$	$0,166.10^{-3}$ $(0,0105)$	$-0,0182$ $(0,0321)$	$-0,0481$ $(0,0688)$
Other (para)med. means	$0,835.10^{-2}$ $(0,356.10^{-2})$	$0,0589$ $(0,0273)$	$0,970.10^{-2}$ $(0,0837)$	$-0,128$ $(0,180)$
Fac. index	$0,360.10^{-3}$ $(0,228.10^{-3})$	$-0,226.10^{-3}$ $(0,175.10^{-2})$	$-0,784.10^{-2}$ $(0,536.10^{-2})$	$-0,0190$ $(0,0115)$
R^2	0,993	0,999	0,999	0,999
N	107	107	107	107
$\bar{R}^2$	0,992	0,999	0,999	0,999

Continuation table 10: Estimation results of the CES production function (Feldstein method).

Inputs	ρ = 0,1							
	ν = 0,5		ν = 1,0		ν = 1,5		ν = 2,0	
Registered nurses	0,0593	(0,159)	0,0509	(0,0253)	-0,0489	(0,0454)	-0,152	(0,0743)
Student nurses	$-0,261.10^{-2}$	$(0,489.10^{-2})$	-0,0122	$(0,776.10^{-2})$	-0,0214	(0,0139)	-0,0286	(0,0228)
Other nursing staff	$0,701.10^{-4}$	$(0,313.10^{-2})$	$-0,649.10^{-3}$	$(0,497.10^{-2})$	$-0,358.10^{-2}$	$(0,892.10^{-2})$	$-0,676.10^{-2}$	(0,0146)
Paramedical staff	0,0195	$(0,906.10^{-2})$	0,0119	(0,0144)	-0,0279	(0,0258)	-0,0679	(0,0422)
Beds	-0,932.10	(0,0221)	0,242	(0,0350)	0,580	(0,0628)	0,867	(0,103)
Specialists	-0,0390	$(0,931.10^{-2})$	0,0108	(0,0148)	0,135	(0,0265)	0,252	(0,0433)
Drugs and dress.	$0,739.10^{-2}$	$(0,971.10^{-2})$	$0,349.10^{-2}$	(0,0154)	-0,0142	(0,0277)	-0,0320	(0,0452)
Other (para)med. means	0,0580	(0,0250)	0,0786	(0,0397)	$0,614.10^{-2}$	(0,0712)	-0,0779	(0,116)
Fac. index	$0,595.10^{-2}$	$(0,491.10^{-2})$	$-0,135.10^{-2}$	$(0,780.10^{-2})$	-0,0178	(0,0140)	-0,0328	(0,0229)
R^2	0,998		0,999		0,999		0,999	
N	107		107		107		107	
$\bar{R}^2$	0,998		0,999		0,999		0,999	

Inputs	ρ = -0,1							
	ν =		ν =		ν =		ν =	
Registered nurses	14,481	(4,365)	0,516	(0,282)	-0,168	(0,171)	-0,309	(0,162)
Student nurses	-0,0798	(1,845)	-0,0975	(0,119)	-0,0672	(0,0723)	-0,0545	(0,0685)
Other nursing staff	1,0668	(1,282)	0,0251	(0,0828)	-0,0116	(0,0502)	-0,0175	(0,0476)
Paramedical staff	7,164	(2,883)	0,171	(0,186)	-0,147	(0,113)	-0,207	(0,107)
Beds	-2,983	(4,561)	1,919	(0,295)	1,604	(0,179)	1,410	(0,169)
Specialists	-12,025	(3,003)	0,158	(0,194)	0,589	(0,118)	0,640	(0,112)
Drugs and dress.	0,527	(0,504)	0,0190	(0,0326)	$-0,512.10^{-2}$	(0,0198)	-0,0100	(0,0187)
Other (para)med. means	2,779	(1,290)	0,126	(0,0834)	$-0,330.10^{-2}$	(0,0506)	-0,0311	(0,0479)
Fac. index	1,008	(2,398)	-0,0377	(0,155)	-0,0835	(0,0940)	-0,0895	(0,0891)
R^2	0,998		0,999		0,999		0,999	
N	107		107		107		107	
$\bar{R}^2$	0,998		0,999		0,999		0,999	

Continuation table 10: Estimation results of the CES production function (Feldstein method).

Inputs	$\rho = -0,2$							
	$\nu = 0,5$		$\nu = 1,0$		$\nu = 1,5$		$\nu = 2,0$	
Registered nurses	229,434	(73,816)	1,676	(0,935)	-0,290	(0,328)	-0,424	(0,236)
Student nurses	9,566	(35,405)	-0,142	(0,449)	-0,0826	(0,157)	-0,0555	(0,113)
Other nursing staff	31,294	(26,255)	0,197	(0,332)	$-0,500.10^{-2}$	(0,116)	-0,0190	(0,0840)
Paramedical staff	134,616	(52,830)	0,626	(0,669)	-0,327	(0,234)	-0,350	(0,169)
Beds	-47,672	(67,847)	5,325	(0,860)	2,613	(0,301)	1,757	(0,217)
Specialists	-218,582	(55,757)	0,526	(0,707)	1,226	(0,247)	1,0179	(0,178)
Drugs and dress	3,729	(3,678)	0,0332	(0,0466)	$-0,113.10^{-2}$	(0,0163)	$-0,424.10^{-2}$	(0,0118)
Other (para)med. means	19,330	(9,460)	0,150	(0,120)	$-0,773.10^{-2}$	(0,0420)	-0,0206	(0,0303)
Fac. index	1,030	(54,308)	-0,197	(0,688)	-0,172	(0,241)	-0,140	(0,174)
R^2	0,999		0,999		0,999		0,998	
N	107		107		107		107	
$\bar{R}^2$	0,999		0,999		0,999		0,998	

*Table 11. Output elasticity of beds and registered nursing staff for the average hospital (Feldstein-method models).**

ρ \ ν	0,5	1,0	1,5	2,0	
0,3	-0,18	0,68	1,37	2,05	beds
	(0,17)	(0,10)	(0,15)	(0,25)	
	5,50	0,18	-0,13	-0,42	registered nursing staff
	(0,13)	(0,09)	(0,12)	(0,20)	
0,2	-0,4	0,69	1,41	2,13	beds
	(0,16)	(0,10)	(0,15)	(0,26)	
	0,39	0,17	-0,13	-0,43	registered nursing staff
	(0,13)	(0,08)	(0,13)	(0,21)	
0,1	-0,07	0,69	1,44	2,19	beds
	(0,16)	(0,10)	(0,16)	(0,26)	
	0,48	0,17	-0,14	-0,44	registered nursing staff
	(0,13)	(0,08)	(0,13)	(0,22)	
-0,1	-0,10	0,68	1,45	2,23	beds
	(0,18)	(0,10)	(0,16)	(0,27)	
	0,44	0,16	-0,13	-0,42	registered nursing staff
	(0,13)	(0,09)	(0,13)	(0,22)	
-0,2	-0,12	0,66	1,43	2,20	beds
	(0,17)	(0,11)	(0,16)	(0,27)	
	0,16	0,06	-0,04	-0,15	registered nursing staff
	(0,14)	(0,09)	(0,14)	(0,22)	

* Between brackets are shown the standard deviations given the values of ρ and ν.
These are calculated as follows:

$$\frac{\partial Q}{\partial X_j} \cdot \frac{X_j}{Q} = \nu \cdot \theta_j \cdot \frac{X_j^{-\rho}}{Q^{-\rho/\nu}}$$

IV.2.3.1. Estimation of CES production functions with a modified Feldstein method

A modified Feldstein method will be applied in this subsection, a nonlinear regression analysis in the next.
The Feldstein method contains some inconsistencies. The first step attempts to explain $Q^{-\rho/\nu}$ as well as possible while the second step is an effort to explain Q.

The first step goes well with the following statistical model:

$$\left.\begin{aligned} &Q_j^{-\rho/\nu} = \sum_{i=1}^{p} \theta_i X_{ij}^{-\rho} + \varepsilon_j \quad (j = 1 \dots N) \\ &\varepsilon_1, \dots, \varepsilon_N \text{ are independent, with } N(0,\sigma^2) \text{distribution} \end{aligned}\right\} \quad (1)$$

where: Q_j = the observed output of hospital j

X_{ij} = the given value for the i^{th} input of hospital j.

We can estimate this model itself in two steps with the aid of the maximum likelihood method (see Box and Cox,1964). The first step is identical with the first step of the Feldstein method. In the second step, ρ and ν are estimated by minimizing:

$$f\ (\rho/\nu) = \frac{\hat{\sigma}_\varepsilon^2\ (\rho,\nu)}{(Q^{-\rho/\nu})^2\ \cdot \frac{\rho^2}{\nu^2}} \qquad (2)$$

($f\ (\rho,\nu)$ is σ_e^2 when $\rho = 0$)

In this:

$$- \hat{\sigma}_\varepsilon^2\ (\rho,\nu) = \frac{1}{n-p} \sum_{j=1}^{N} (Q^{-\rho/\nu} - \widehat{Q_i^{-\rho/\nu}})^2 \qquad (3)$$

is an unbiased estimator of σ_e^2 with the assumed ρ and ν, based on the ordinary least-squares estimation of model (1).

$- \tilde{Q} = \left(\prod_{j=1}^{N} Q_j \right)^{1/N}$, geometric mean of the observed outputs $Q_1, \dots, Q_N$.

Before going further into this, we note that the minimizing of (2) over ρ and ν is intuitively justified as a method of estimating ρ and ν. At the real value of ρ and ν, $\hat{\sigma}_\varepsilon^2(\rho,\nu)$ will be small, but the values of $\sigma_\varepsilon^2(\rho,\nu)$ at different (ρ,ν) can not be directly compared with each other because this is a matter of difference in the dependent variables. However, if we divide $\sigma_\varepsilon^2(\rho,\nu)$ by

$\frac{\rho^2}{\nu^2} \cdot \left(\widehat{Q^{-\rho/\nu}}\right)^2$, we get a quantity free of dimension which is indeed good for comparison purposes.

Suppose now that $\lambda(\rho,\nu,\Theta_1,\dots,\Theta_p,\sigma_\varepsilon^2 | Q_1,\dots,Q_n)$ is the likelihood function for the parameters of model (1) with the observed $Q_1,\dots,Q_n$.

From Box and Cox (1964) it appears that:

$$\max_{\theta_1,\ldots,\theta_p,\sigma^2} \log \lambda\ (\rho,\nu,\theta_1,\ \ldots,\ \theta_p,\sigma_\varepsilon^2 \mid Q_1,\ \ldots,\ Q_n) = -\frac{n}{2} \log f\ (\rho,\nu) + \text{constant}$$

We define $Z = 2 \log \lambda$

$$Z = -n \log \hat{\sigma}_e^{\,2}\ (\rho,\nu) - n\ \frac{\rho}{\nu} \sum_{j=1}^{N} \log Q_j + n \log (\frac{\rho}{\nu}) + \text{constant} \tag{5}$$

This is also valid with $\rho = 0$, where it must be noted that if ρ converges to 0, with a given ν, model (1) continuously changes into the Cobb-Douglas model:

$$\left.\begin{array}{l} \log Q_j = \alpha_0 + \sum_{i=1}^{p} \alpha_i \log X_{ij} + e_i;\ j= 1,\ \ldots,\ N;\ \sum_{i=1}^{p} \alpha_i=\nu \\ e_1,\ \ldots,\ e_N \text{ are independent, with } N(0,\sigma_e^{\,2} \text{ distribution} \end{array}\right\} \tag{6}$$

Suppose $\hat{\rho}$ and $\hat{\nu}$ are the values of ρ and ν that f (ρ,ν) minimizes or (5) maximizes. Then, according to the theory of maximum likelihood estimators (see, for example, Mood, Graybill and Boes 1974, pp. 440-442), an asymptotic 100 $*(1-\alpha\%)$ confidence interval for (ρ,ν) can be given as those ρ's and ν's which satisfy:

$$n \log f\ (\rho,\nu) - n \log f\ (\hat{\rho},\hat{\nu}) \leq \chi_2^2\ (1-\alpha) \tag{7}$$

Here, χ_2^2 $(1-\alpha)$ is the 100.$(1-\alpha)$ percentile of the χ^2-distribution with 2 degrees of freedom.
Table 12 gives the value of Z for different combinations of ρ and ν.

Table 12. Value of Z with different combinations of ρ and ν

ρ \ ν	0,5	1,0	1,5	2,0
0,3	132,04	180,31	139,23	91,46
0,2	135,35	181,55	139,45	92,05
0,1	139,41	181,99	140,15	92,51
0,0	141,16	181,74	139,89	92,81
-0,1	140,69	180,91	139,48	93,01
-0,2	137,88	179,60	139,84	93,14

The maximum of Z lies in the neighbourhood of $\rho = 0,1$ and $\nu = 1,0$.
We can more accurately determine the ρ and ν which maximize by applying a quadratic curve to the points which lie around these values of ρ and ν.
To this end we have approximated Z with the equation

$$Z \approx -34,5\ \rho^2 - 168,84\ \nu^2 + 0,20\ \rho.\nu + 5,75\ .\ \rho + $$
$$+ 338,40\ .\ \nu + 12,18.$$

On this basis we can calculate the ρ and ν which maximize Z

$$\left.\begin{array}{l} \frac{\partial Z}{\partial \rho} = -69\ .\ \rho + 0,20\ .\ \nu + 5,75 = 0 \\ \\ \frac{\partial Z}{\partial \nu} = -337,68\ .\ \nu + 0,20\ .\ \rho + 338,\ 40 = 0 \end{array}\right\} \rightarrow \boxed{\begin{array}{l} \rho_{max} = 0,0862 \\ \nu_{max} = 1,0022 \end{array}}$$

The parameter estimates which belong to ρ_{max} and ν_{max} can be approximately deduced from Table 10.
As we said, there is also the possibility of constructing a simultaneous confidence interval for ρ and ν (7). This confidence interval is represented in grafic 7 with $\alpha = 0,05$ $(\chi^2_2 = 5,99)$.
With a simultaneous confidence of 95%, ρ lies between -0,33 and 0,50 and ν between 0,82 and 1,19. From this it appears that ν is determined much better than ρ.
The results, as we will see in the following subsection, do not conflict with the results of the nonlinear regression analysis.

IV.2.3.2. Estimation of CES production functions with nonlinear regression analysis

The CES specification can also be estimated with the aid of nonlinear regression analysis.
We go out, then, from the following model:

$$\ln Q_j = -{}^{\nu}/\rho \log \left(\sum_{i=1}^{p} Q_i\, X_{ij}^{-\rho} \right) + \varepsilon_j;\ j = 1, \ldots, N$$

$\varepsilon_1, \ldots, \varepsilon_N$ independent, with $N(0, \sigma_e^2)$ distribution
As ρ converges to zero, this model passes over into the Cobb-Douglas specification.
The error term in this model deviates from that in model (1) (page 89). This is because the Cobb-Douglas specification is not a special case of the latter model. In this model one cannot assume that σ_e^2 is constant (heteroscedasticity). The disturbance will be bigger in larger hospitals than in smaller hospitals. However in the present model the disturbance will be homoscedastic because of the logarithmic transformation.

Grafic 7: Simultaneous confidence region of ρ and v (α_1 = 10%; α_2 = 5%).

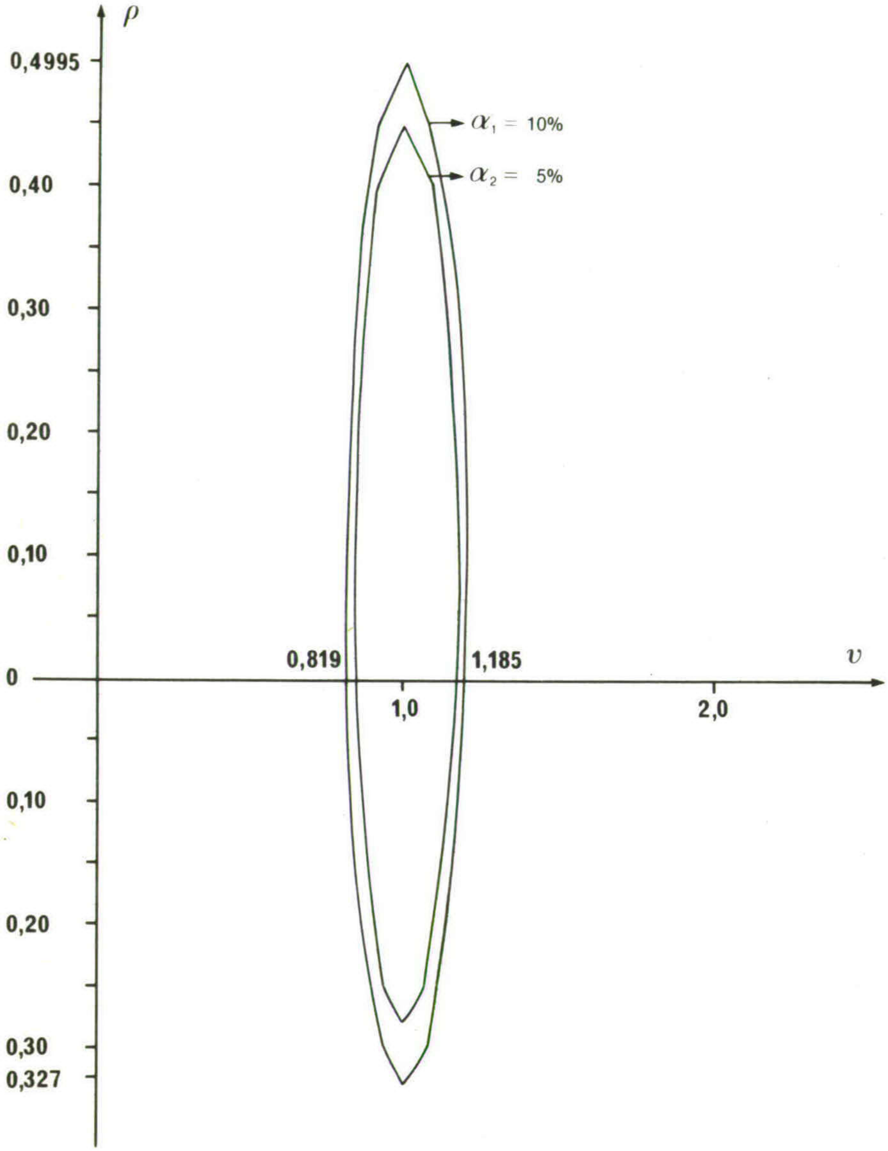


Table 13. Estimation results of CES production function for the weighted admissions with the aid of nonlinear regression (logarithmic specification)

	estim. coeff.	estim. stand. dev.
ρ	0,620	(0,817)
ν	1,009	(0,044)
Reg. nurses	0,1703	(0,0912)
Stud. nurses	-0,012	(0,034)
Other nurses staff	-0,00167	(0,0146)
Paramed. staff	0,0372	(0,0487)
Beds	0,661	(0,106)
Specialists	0,055	(0,062)
Fac. index	-0,011	(0,028)
Drugs and Dress.	0,00365	(0,0147)
Other (para)med.means	0,0938	(0,0534)
R^2	0,94	
N	107	
$\bar{R}^2$	0,94	

We estimated the model on transformed data via the Marquardt algorithm (Daniël and Wood,1971).
The substance of this transformation is that the averages are substracted from the original data. This implies then that the Θ_i's - up until ν, which is nearly 1 - can be interpreted directly as the output elasticities of the respective inputs.
The estimated ν does not deviate significantly from that which is obtained with the aid of the modified Feldstein method.
The estimated ρ is 0,620, yet has a relatively large standard deviation.
Two input parameters are significant at the 95% level, namely, that of registered nursing staff and that of the number of beds. These estimates do not deviate significantly from those which are obtainded with the aid of the Cobb-Douglas specification.
The estimates are calculated with the aid of an iterative procedure which stops looking for a better solution when a (local) optimum is reached. It is now possible that, with another (local) optimum, the estimates of the parameters belonging to it deviate from the results as shown above. Above, no conditions were imposed with regard to the range of the parameters. Several estimation experiments have been executed by v/d Ven (student at the Catholic University at Tilburg) and Reitsma, who did a lot of the computer programming (v/d Ven, 1979).
They concern the imposition of restrictions on the ρ,ν and the Θ's (for example, $\Theta>0$), going out from different starting values and reduction of the number of inputs.
In these experiments, generally speaking, the estimated ρ lay close to 0(otherwise with a relatively high estimated standard deviation) and the estimated ν lies in the neighbourhood of 1.
The results obtained from nonlinear regression analysis give no grounds for rejecting the Cobb-Douglas specification.

The findings from nonlinear regression analysis are also in agreement with those from the modified Feldstein method. We will estimate the translog specification in the following section. This is a more general production function than the Cobb-Douglas and CES specifications.

IV.3. Estimation translog production functions

The form and the properties of the translog model were dealt with in Chapter II. Here, translog models will be estimated for weighted admissions (IV.3.1.), weighted patient days (IV.3.2.) and intermediary production (IV.3.3.).
In IV.4., some conclusions will be given in regard to the different model specifications tested.

IV.3.1. Estimation translog production functions for the weighted admissions

The translog model has the following form:

$$\ln Q_z = a_o + \sum_{i=1}^{p} a_i \cdot \ln X_{iz} + \sum_{\substack{i=1 \\ i\leq j}}^{p} \sum_{j=1}^{p} b_{ij} \ln X_{iz} \ln X_{jz} + \varepsilon_z$$

where: p = number of inputs
z = 1,..,N; N = number of hospitals
ε_z = residual of hospital z

It is assumed that the residual terms are independent of each other, with N $(0,\sigma_e{}^2)$. With this logarithmic transformation of the original variables there is no heteroscedasticity. (Appendix IV.4).
Many alternatives are estimated. Table 14 shows the results of the model for the weighted admissions and 5 inputs. The explanatory power ($\bar{R}^2$) is 0,93 and is nearly as high as with the Cobb-Douglas specification. Of the individual parameters, none is significant at the 90% level. This is related, among other things, with multicollinearity between explanatory variables. The correlation matrix of the explanatory variables and of the estimators is shown in Appendix IV.3. We will return to this later. Only the linear term of the number of beds is in some degree significant (t = 1,73).
We can test to what extent the model reduction of the translog model to a Cobb-Douglas specification leads to information loss with an F-test (see Draper and Smith, 1966). With this we test the null hypothesis that all coefficients of quadratic and cross terms are equal to 0. The observed F for all cross terms and quadratic terms of the 5 inputs (Table 14) is 1,25 (with 15 and 86 degrees of freedom). To this belongs a tail probability of 25%, so that we can not reject the null hypothesis (that the Cobb-Douglas model is valid). A factor here is undoubtedly the great number of parameters to be estimated in the translog model.
The above test is a rough test for all inputs.

Table 14. Results regression-analysis translog production function for weighted admissions and 5 inputs.

Variables	estim. coeff.	estim. stand. dev.
1. Const.	5,29	(7.29)
2. Staff	-2,75	(3.43)
3. Beds	6,23	(3.61)
4. Spec.	1,39	(1.88)
5. Fac.	-0,35	(1.27)
6. Drugs	0,026	(1.21)
7. $(\text{Staff})^2$	-0,17	(0.74)
8. $(\text{Beds})^2$	-0,84	(0.91)
9. $(\text{Spec.})^2$	-0,26	(0,23)
10. $(\text{Fac.})^2$	0,040	(0,079)
11. $(\text{Drugs})^2$	0,023	(0.068)
12. Staff * Beds	0,35	(1.47)
13. Staff * Spec.	0,12	(0.60)
14. Staff * Fac.	-0,058	(0.31)
15. Staff * Drugs	0,20	(0.37)
16. Beds * Spec.	1,23	(0.70)
17. Beds * Fac.	0,10	(0.39)
18. Beds * Drugs	-0,15	(0.35)
19. Spec. * Fac.	-0,28	(0.22)
20. Spec. * Drugs	-0,29	(0.19)
21. Fac. * Drugs	0,061	(0.123)
R^2	0,94	
N	107	
$\bar{R}^2$	0,93	

Therefore a number of F-tests are executed that are concerned with one or two inputs. In this way we can, for example, test the null hypothesis that the output elasticity of the i^th^ input is constant through testing whether $b_{ij} = 0$ for all j. These results are given in table 15.

Table 15. F-values for testing constant output elasticities per input (number of degrees of freedom [5,86]).

output elasticity	right tail probability	$F_{\text{calcul.}}$
Staff	0,80	0,46
Beds	0,05**	2,30
Spec.	0,08*	1,99
Fac.	0,90	0,24
Drugs	0,44	0,79

** significant at 5% level

* significant at 10% level

There are significant results with regard to the number of beds (at the 95% level) and the number of specialists (at the 90% level). That is, with regard to output elasticity the production structure deviates from the Cobb-Douglas structure.
In the same manner we can test for each pair of inputs whether their substitution elasticity deviates (at some set of input-levels) from 1; that is, for inputs j and k we test the null hypothesis $b_{kk} = 0$, $b_{jk} = 0$ and $b_{jj} = 0$. This means that the null hypothesis is: $e_{jk} = 1$ for all inputlevels (η_i). For this, an F-test is again applicable.
(From the formula for e_{jk} (page 49), it follows that if b_{jj}, b_{jk} and b_{kk} are all equal to zero, the elasticity of substitution between j and k is equal to 1 for all values of η_i).
Table 16 gives the F-values for the different elasticities of substitution.

Table 16. F-values for testing whether elasticities of substitution are equal to 1 for all levels of the inputs (number of degrees of freedom [3,86]).

Elasticity of substitution	$F_{calcul.}$	right tail probability
Staff and Beds	2,16	0,09*
Staff and Spec.	0,42	0,74
Staff and Drugs	0,32	0,81
Staff and Fac.	1,02	0,39
Beds and Spec.	2,29	0,08*
Beds and Drugs	1,24	0,30
Beds and Fac.	1,76	0,16
Spec. and Drugs	0,86	0,47
Spec. and Fac.	2,44	0,07*
Fac. and Drugs	1,01	0,39

* significant at 10% level.

Going out from a 90% confidence level, the elasticiteis of substitution between staff and beds, between beds and specialists, between specialists and facility index and (at 80% confidence level) between beds and facility index deviate significantly from 1. Testing the null hypothesis that $b_{jj}\alpha_k^2 - b_{jk}\alpha_j\alpha_k + b_{kk}\alpha_j^2 = 0$, does not lead to rejecting the null hypothesis for any combination of j and k. If $b_{jj}\alpha_k^2 - b_{jk}\alpha_j\alpha_k + b_{kk}\alpha_j^2 = 0$, then $e_{jk} = 1$ (see formula on page 49).
With this it must be noted that, assuming the Cobb-Douglas model, there is a good chance that some of the many tests will yield significant results.
A disadvantage of the translog model is that the number of parameters to be estimated increases quadratically with the number of inputs. In a specification in which the facility index and drugs are eliminated, the same results with regard to staff are found for the number of beds and the number of specialists.
In table 17, staff is subdivided into four categories, namely, registered nurses, student nurses, other nursing staff and paramedical staff. Because the number of parameters to be estimated would be extremely high, one input - namely, drugs - is omitted.

Table 17. Results regression-analysis translog production function for the weighted number of admissions and 7 inputs

variables	estim. coeff.	estim. stand. dev.
Constant	5,09	(6,89)
RN	-1,99	(3,40)
StN	-1,28	(2,20)
ON	0,049	(0,609)
PM	1,27	(1,45)
Beds	7,97	(5,53)
Spec.	-4,36	(2,37)
Fac.	-2,36	(1,38)
$(RN)^2$	-0,470	(0,426)
$(StN)^2$	0,0024	(0,0864)
$(ON)^2$	0,0253	(0,0322)
$(PM)^2$	0,052	(0,120)
$(Beds)^2$	-1,48	(1,12)
$(Spec.)^2$	0,066	(0,242)
$(Fac.)^2$	-0,0813	(0,0822)
RN * StN	0,156	(0,562)
RN * ON	0,018	(0,197)
RN * PM	0,598	(0,359)
RN * Beds	0,94	(1,23)
RN * Spec.	0,052	(0,494)
RN * Fac.	-1,115	(0,340)
StN * ON	-0,056	(0,154)
StN * PM	0,186	(0,349)
StN * Beds	0,125	(0,758)
StN * Spec.	-0,146	(0,432)
StN * Fac.	-0,019	(0,137)
ON * PM	-0,006	(0,105)
ON * Beds	0,029	(0,231)
ON * Spec.	-0,067	(0,119)
ON * Fac.	0,0595	(0,0568)
PM * Beds	-0,459	(0,516)
PM * Spec.	-0,772	(0,299)
PM * Fac.	0,058	(0,165)
Beds * Spec.	1,265	(0,807)
Beds * Fac.	1,183	(0,475)
Spec. * Fac.	0,122	(0,256)
R^2	0,96	
N	107	
$\bar{R}^2$	0,94	

Testing the null hypothesis that all (28) coefficients of quadratic and cross terms are zero gives an F-value of 1,14 with 28 and 71 degrees of freedom. To this belongs a right-tail probability of 30%, so that the null hypothesis can not be rejected.
In the same manner as before, one can also undertake tests for the null hypothesis "$b_{ij} = 0$ for every j" (thus one test for each input i) and for the null hypothesis "$b_{jj} = b_{jk} = b_{kk} = 0$" (thus one test for each pair of inputs j and k).

For some inputs (registered nursing staff, facility index), the null hypothesis is rejected at the 90% level.

A translog production function suits the data better than a Cobb-Douglas specification on a number of points. This is not the case for all inputs, however, so that a careful reduction of the number of variables in the translog specification will not lead to information loss. Some model reductions are executed but what follows is based on the models given above.

Output elasticities and elasticities of substitution

Table 18 gives the output elasticities and elasticities of substitution belonging to the translog model of table 14.

Table 18. Elasticities of substitution of the translog model for the weighted admissions with 5 inputs at the average input levels

Inputs		output-elasticity		elasticity of substitution 1	2	3	4	5
Staff	(1)	0,34	(0,15)	.				
Beds	(2)	0,64	(0,15)	0,31	.			
Spec.	(3)	0,02	(0,08)	0,04	0,04	.		
Fac.	(4)	0,00	(0,07)	-0,15	-0,17	-0,07	.	
Drugs	(5)	0,04	(0,05)	0,92	-2,71	0,17	-0,36	.

The first column shows the output elasticities of the 5 inputs, on the average input levels. These appear to be almost identical to the average output elasticities on the basis of the Cobb-Douglas specification (table 7).
The elasticities of substitution are also represented in table 18. In the translog specification we see elasticities of substitution which deviate from 1. The elasticity of substitution between staff and beds is 0,31, between specialists and staff is 0,04, and between the number of beds and the number of specialists is 0,04. Note that some elasticities of substitution are negative. We will return later to the statistical significance of the elasticities of substitution.

Table 19. Elasticities of substitution and output elasticities of the translog model for the weighted admissions with 7 inputs.

inputs		output elasticity		elasticity of substitution 1	2	3	4	5	6	7
RN	(1)	0,27	(0,15)	.						
StN	(2)	0,24	(0,12)	0,31	.					
ON	(3)	0,05	(0,04)	1,29	4,27	.				
PM	(4)	0,19	(0,10)	0,21	0,65	33,86	.			
Beds	(5)	0,50	(0,22)	0,13	0,31	1,40	1,15	.		
Spec.	(6)	-0,12	(0,11)	1,03	1,26	3,62	-0,06	0,14	.	
Fac.	(7)	-0,17	(0,11)	-0,04	-0,36	-0,97	0,37	0,27	2,45	.

Table 19 shows the elasticities of substitution and output elasticities of the translog model in which drugs were omitted and nursing staff subdivided into four categories. There are several great differences with the output elasticities in the Cobb-Douglas model (table 9). In the translog model, significant output elasticities appear not only for registered nursing and paramedical staff but student nursing staff also has a significant output elasticity with respect to the weighted admissions. This agrees with the related conclusion, above, that a Cobb-Douglas specification is possibly too limited a function for this more disaggregated data, and that a translog function offers better possibilities in quantifying a production structure which is more complicated in a number of aspects.

The above calculated output elasticities are based on the average input levels. The translog function implies that the output elasticities can be dependent of the input levels. Table 20 shows the output elasticities and the standard deviations for different input levels.

Table 20. Output elasticities of the inputs with respect to the weighted admissions at the average input levels per function group (translog model).

	output elasticity				
inputs	function-group I	function-group II	function-group III	function-group IV	total
Staff	0,18 (0,19)	0,28 (0,17)	0,37 (0,15)	0,51 (0,27)	0,34 (0,15)
Beds	0,82 (0,19)	0,64 (0,15)	0,60 (0,16)	0,52 (0,26)	0,64 (0,15)
Spec.	-0,08 (0,13)	-0,05 (0,11)	0,08 (0,08)	0,12 (0,12)	0,02 (0,08)
Fac.	0,03 (0,07)	0,04 (0,08)	0,00 (0,08)	-0,04 (0,10)	0,01 (0,07)
Drugs	0,06 (0,07)	0,08 (0,05)	0,02 (0,05)	-0,01 (0,09)	0,04 (0,05)

With this, we take as our starting point the average input levels of the four function groups of general hospitals as specified in the BKZ report, part 3 (van Aert and van Montfort 1976). This typology of hospitals is based on the composition of the medical staff. From function group I to function group IV, the composition of the medical staff is always larger. From table 20 it appears that differences are to be found in the output elasticities, especially with regard to staff and the number of beds. The output elasticities of the staff (nursing and paramedical staff) increases notably from function group I to function group IV. With regard to beds, we see the opposite. This means that an increase in staff of, for example, 1% in function group I is related to a much smaller increase in output (0,18%) than the same increase in percentage in staff in function group IV. In the latter case output increases by 0,51%.
In Chapter I the output elasticities for the staff, the beds and the number of specialists at different input levels are graphically represented per function group. This shows the

differentiated character of the production structure. Within a function group the differences in the output elasticities are statistically more significant than between function groups (Figure 6). The output elasticities per input at different input levels and their standard deviations are given in Appendix IV.5.
Interesting is the relationship between the number of specialists and the number of beds. When one raises the number of specialists within the empirical range of a certain function group, the output elasticity of the number of beds increases significantly. This implies that an increase in the number of beds results in a higher increase in the output (in terms of weighted admissions) than does an increase in the number of specialists per bed. In other words, the marginal productivity of the number of beds and the number of staff members increases with an increase in the number of specialists.
The variation in the levels of the facility index and drugs has little influence on the output elasticities.
The same calculations are also executed for the more disaggregated model. Table 21 gives the output elasticities of the 7 inputs per function group.

Table 21. Output elasticities of 7 inputs with respect to weighted admissions at the average input levels per function group.

	output elasticity				
Inputs	function-group I	function-group II	function-group III	function-group IV	total
RN	0,48 (0,18)	0,23 (0,13)	0,19 (0,12)	0,18 (0,24)	0,27 (0,15)
StN	-0,05 (0,14)	0,12 (0,12)	0,27 (0,10)	0,43 (0,15)	0,24 (0,12)
ON	0,04 (0,06)	0,05 (0,04)	0,04 (0,03)	0,09 (0,06)	0,05 (0,04)
PM	0,09 (0,10)	0,18 (0,09)	0,12 (0,08)	0,06 (0,15)	0,19 (0,10)
Beds	0,42 (0,24)	0,51 (0,18)	0,50 (0,17)	0,47 (0,32)	0,50 (0,22)
Spec.	-0,16 (0,15)	-0,10 (0,11)	0,05 (0,09)	0,03 (0,31)	-0,12 (0,11)
Fac.	0,04 (0,07)	-0,07 (0,07)	-0,12 (0,09)	-0,10 (0,14)	-0,17 (0,09)

From this, we see a striking difference with the Cobb-Douglas specification (table 9).
In function groups I and II and, in somewhat lesser degree, function group III, the output elasticity of the registered nursing staff is statistically significant. The student nursing staff is of particular importance, especially in function groups III and IV. It appears from Appendix IV.6 that the output elasticities of some staff categories within a function group shows us rather great differences.
From the above calculations concerning the output elasticities of the inputs, it can be concluded that the Cobb-Douglas specification is too rough a model on a number of points.
The translog function shows us interesting nuances for some output elasticities at different input levels.
We can also study the same effect with regard to the elasticity of substitution of the inputs (e_{jk}).

Table 22 shows the elasticities of substitution calculated at the average input levels per function group.

Table 22. Elasticities of substitution between the inputs in the model of the weighted admissions.

	Functiongroup				
	I	II	III	IV	total
Staff and Beds	0,27	0,29	0,30	0,28	0,30
Staff and Spec.	-0,10	-0,09	0,20	0,20	0,04
Staff and Fac.	-0,50	-1,39	0,05	0,33	-0,15
Staff and Drugs	0,40	0,53	-3,33	0,15	0,92
Beds and Spec.	-0,31	-0,14	0,09	0,11	0,04
Beds and Fac.	-0,61	-5,40	0,05	0,28	-0,17
Beds and Drugs	21,09	3,39	-0,55	0,19	-2,71
Spec. and Fac.	-0,10	0,00	0,07	-0,24	-0,07
Spec. and Drugs	0,02	-0,02	-0,18	1,36	0,17
Fac. and Drugs	10,48	1,47	0,03	0,38	-0,36

From a comparison of the elasticities in the different function groups, great differences are to be observed for some, little or no differences for others. The elasticity of substitution between the number of staff members and the number of beds is nearly the same in all function groups. The e_{jk} between the number of staff members and the number of specialists is negative in function I and II, yet positive in III and IV. Such a comparison is limited to the estimated values of the elasticities of substitution at different input levels. If one wants to arrive at statistical statements, however, then the distribution of the estimator of the elasticities of substitution must also be involved here, in particular its standard deviation must be estimated. Determining this standard deviation is not easy.
By an analytical method one obtains an approximation (Appendix IV.7). The calculated standard deviations are high in view of the estimated elasticities, so that wide confidence intervals result. This means that no accurate conclusions about the size of the elasticities of substitution can be done.
An alternative is a simulation experiment. This experiment is described in Appendix IV.7. It is again concluded that an accurate determination of the size of the elasticities of substitution is not possible. There are, however, indications that some elasticities of substitution are smaller than 1, in contrast to what is assumed with the Cobb-Douglas production function.
Table 19 gave the elasticities of substitution among the different staff categories themselves and with the other inputs. From this it can be deduced that there are substitution possibilities between the student nursing staff and the other nursing staff, between the registered nursing staff and the other nursing staff. The substitution possibilities are smaller between registered and student nursing staff and between registered and paramedical staff. The substitution possibilities of the number of beds and the staff categories are concentrated especially on the paramedical staff and the other nursing staff.

The elasticities of substitution between the number of specialists and the registered nursing staff is 1,03, and with the other nursing staff is 3,62. Just as above, an accurate determination of the elasticities on the basis of the estimated models is not easily possible.

Scale effects

The estimated production functions provide the opportunity to get insight into the scale effects in the technical production area. Appendix IV.8 shows how these scale effects and the standard deviations for the different types of production functions can be calculated.
In the foregoing it was concluded with regard to the Cobb-Douglas production function that, taking the weighted admissions as a starting point, there are no significant advantagious or disadvantageous scale effects. In table 23 the scale effects with related standard deviation per function group are calculated.

Table 23. Scale effects with related standard deviations per function group going out from the translog function for the weighted admission (Σ = sum of output elasticities; σ_Σ = standard deviation of Σ).

Decrease/ increase inputlevels	Function-group I Σ	σ_Σ	Function-group II Σ	σ_Σ	Function-group III Σ	σ_Σ	Function-group IV Σ	σ_Σ
- 50%	0,92	(0,21)	0,90	(0,18)	0,98	(0,11)	1,02	(0,08)
- 45%	0,91	(0,19)	0,90	(0,16)	0,98	(0,09)	1,03	(0,07)
- 40%	0,93	(0,18)	0,93	(0,15)	0,99	(0,08)	1,04	(0,07)
- 35%	0,95	(0,16)	0,95	(0,13)	1,00	(0,07)	1,05	(0,06)
- 30%	0,95	(0,15)	0,95	(0,12)	1,01	(0,06)	1,06	(0,06)
- 25%	0,96	(0,14)	0,95	(0,11)	1,02	(0,05)	1,06	(0,07)
- 20%	0,98	(0,13)	0,97	(0,10)	1,03	(0,05)	1,08	(0,08)
- 15%	0,98	(0,12)	0,97	(0,09)	1,04	(0,05)	1,09	(0,08)
- 10%	0,98	(0,11)	0,97	(0,08)	1,04	(0,05)	1,10	(0,09)
- 5%	1,00	(0,10)	0,98	(0,07)	1,06	(0,05)	1,11	(0,10)
Average inputlevel	1,01	(0,09)	0,99	(0,06)	1,07	(0,06)	1,10	(0,11)
+ 5%	1,00	(0,08)	0,99	(0,06)	1,06	(0,06)	1,11	(0,11)
+ 10%	1,00	(0,08)	1,01	(0,06)	1,08	(0,07)	1,13	(0,12)
+ 15%	1,03	(0,07)	1,02	(0,05)	1,06	(0,08)	1,13	(0,13)
+ 20%	1,03	(0,07)	1,00	(0,05)	1,09	(0,08)	1,13	(0,14)
+ 25%	1,04	(0,07)	1,01	(0,05)	1,10	(0,09)	1,13	(0,14)
+ 30%	1,04	(0,06)	1,03	(0,06)	1,10	(0,10)	1,14	(0,15)
+ 35%	1,05	(0,06)	1,03	(0,06)	1,11	(0,10)	1,14	(0,16)
+ 40%	1,04	(0,06)	1,04	(0,06)	1,10	(0,11)	1,15	(0,16)
+ 45%	1,05	(0,06)	1,03	(0,07)	1,11	(0,12)	1,15	(0,17)
+ 50%	1,06	(0,06)	1,03	(0,07)	1,11	(0,12)	1,17	(0,17)

It appears from the table that, with respect to the weighted admissions, the scale effects are dependent on the input levels yet the differences are statistically significant to a small degree. This holds within as well as between the function groups. The advantageous scale effects are smaller at lower input levels than at higher input levels. The statistical significance of the differences is not great.
These results lead to the conclusion that the scale effects do not deviate in a statistically significant way from those based on the Cobb-Douglas production function.

IV.3.2. Estimation translog production functions for the weighted patient days

We deal in this section with some translog specifications for the weighted patient days. The estimation results of these two models are given in Tables 24 and 25.

Table 24. Translog model for the weighted patient days and 5 inputs.

Variables	estim. coeff.	estim. stand. dev.
Constant	11,26	(2,64)
Staff	0,0964	(1,5279)
Beds	1,22	(1,77)
Spec.	-0,278	(0,886)
Fac.	-0,243	(0,568)
Drugs	-0,208	(0,295)
$(Pers.)^2$	0,336	(0,391)
$(Bed)^2$	0,119	(0,469)
$(Spec.)^2$	-0,179	(0,127)
$(Fac.)^2$	0,0048	(0,0397)
$(Drugs)^2$	-0,0033	(0,0128)
Staff * Beds	-0,656	(0,794)
Staff * Spec.	0,269	(0,318)
Staff * Fac.	-0,211	(0,170)
Staff * Drugs	-0,0247	(0,116)
Beds * Spec.	0,0734	(0,3721)
Beds * Fac.	0,243	(0,207)
Beds * Drugs	0,0918	(0,118)
Spec. * Fac.	-0,0302	(0,112)
Spec. * Drugs	-0,0302	(0,0647)
Fac. * Drugs	0,0056	(0,0365)
R^2	0,984	
N	107	
$\bar{R}^2$	0,980	

Table 25. Translog model for the weighted patient days and 7 inputs.

Variables	estim. coeff.	estim. stand. dev.
C	16,14	(0,0174)
RN	0,0508	(0,0636)
StN	0,1124	(0,0511)
ON	0,0321	(0,0183)
PM	0,0947	(0,0388)
Beds	0,8332	(0,0978)
Spec.	-0,0029	(0,0457)
Fac.	-0,0533	(0,0392)
$(RN)^2$	-0,0193	(0,2466)
$(StN)^2$	-0,0211	(0,0499)
$(ON)^2$	0,0089	(0,0186)
$(PM)^2$	0,081	(0,969)
$(Beds)^2$	-0,467	(0,649)
$(Spec.)^2$	-0,071	(0,139)
$(Fac.)^2$	-0,0662	(0,0475)
RN * StN	-0,158	(0,325)
RN * ON	-0,043	(0,114)
RN * PM	0,0073	(0,208)
RN * Beds	0,484	(0,710)
RN * Spec.	0,347	(0,286)
RN * Fac.	-0,428	(0,197)
StN * ON	-0,0655	(0,0009)
StN * PM	0,169	(0,202)
StN * Beds	0,187	(0,438)
StN * Spec.	0,0702	(0,2495)
StN * Fac.	-0,0522	(0,0789)
ON * PM	0,0737	(0,0605)
ON * Beds	0,0065	(0,1336)
ON * Spec.	-0,0192	(0,0687)
ON * Fac.	0,0201	(0,0328)
PM * Beds	-0,362	(0,298)
PM * Spec.	-0,159	(0,173)
PM * Fac.	0,0542	(0,0952)
Beds * Spec.	-0,181	(0,467)
Beds * Fac.	0,584	(0,275)
Spec. * Fac.	0,0412	(0,1479)

From the F-tests on the parameters eliminated in the Cobb-Douglas model with regard to the translog model, it appears that the null hypothesis that the eliminated parameters are all equal to zero, can not be rejected. The calculated F-value of the reductions in the model with 5 inputs (table 24) is 0,62. For the model with 7 inputs (table 25) the calculated F-value is 0,86. From application of the F-test to the separate inputs no indication emerges that the Cobb-Douglas structure would be too rough. The F-tests with the model with 7 inputs shows some indication of a more complicated structure. This goes particularly for the number of beds, the paramedical staff and the facility index.

Output and elasticities of substitution

In order to be able to compare the results of the specifications somewhat better, the output elasticities and elasticities of substitution are given in tables 26 and 27.

Table 26. Elasticities of substitution and output elasticities of the translog model for the weighted patient days and 5 inputs.

Inputs		output-elasticity		elasticity of substitution 1	2	3	4	5
Staff	(1)	0,20	(0,10)	.				
Beds	(2)	0,94	(0,11)	-0,33	.			
Spec.	(3)	0,01	(0,06)	0,02	0,02	.		
Fac.	(4)	-0,02	(0,05)	-2,11	0,49	0,01	.	
Drugs	(5)	0,01	(0,03)	0,96	0,59	0,04	-9,24	.

Table 27. Elasticities of substitution and output elasticities of the translog model for the weighted patient days and 7 inputs.

Inputs		output-elasticity		elasticity of substitution 1	2	3	4	5	6	7
RN	(1)	0,05	(0,06)	.						
StN	(2)	0,11	(0,05)	0,12	.					
ON	(3)	0,03	(0,02)	0,13	-6,32	.				
PM	(4)	0,10	(0,04)	0,09	-0,82	0,80	.			
Beds	(5)	0,83	(0,10)	0,07	-0,33	1,20	-1,01	.		
Spec.	(6)	-0,003	(0,046)	0,04	0,11	0,22	0,29	0,13	.	
Fac.	(7)	-0,05	(0,04)	0,03	-0,12	0,46	0,53	1,23	0,05	.

From these it appears that the number of beds (output elasticity = 0,94; σ = 0,11) and the (nursing and paramedical) staff (output elasticity = 0,20; σ = 0,10) are the most important inputs. The Cobb-Douglas specification gives the same average output elasticities. With the Cobb-Douglas specification, however, we do see a significantly negative output elasticity of the facility index (-0,042; σ = 0,019) (table 8).
In the translog model, the output elasticity of the facility index does not deviate significantly from zero.
From table 27 it appears that the student nursing and the paramedical staff have significant output elasticities. In the translog model, the output elasticity of the number of beds is a bit lower than in the Cobb-Douglas specification.
On the basis of the translog models, we can calculate the output elasticities, going out from the averages per function group. These output elasticities and the corresponding standard deviations are given in table 28.

Table 28. Output elasticities of the inputs with regard to weighted patient days at the average input levels per function group (translog model).

Inputs	output elasticity: function-group I	function-group II	function-group III	function-group IV	total
Staff	0,13 (0,12)	0,14 (0,11)	0,20 (0,10)	0,30 (0,16)	0,20 (0,10)
Beds	0,99 (0,11)	0,99 (0,11)	0,94 (0,11)	0,88 (0,17)	0,94 (0,11)
Spec.	0,00 (0,09)	0,02 (0,08)	0,00 (0,06)	-0,01 (0,08)	0,01 (0,06)
Fac.	-0,01 (0,05)	-0,02 (0,05)	-0,02 (0,05)	-0,03 (0,07)	-0,02 (0,05)
Drugs	-0,01 (0,03)	0,01 (0,03)	0,02 (0,03)	0,03 (0,05)	0,01 (0,03)

The output elasticities in function groups I and II show no statistically significant differences. The output elasticity of the staff is indeed significant in function groups III and IV. No significant path of the output elasticities with different input levels is to be discerned within the separate function groups.

There are indeed several differences to be noticed, however, between the translog and Cobb-Douglas specifications (particularly the output elasticity of the facility index and the paramedical staff), with the preference going to the first. Table 29 gives the elasticities of substitution at the average input levels per function group.

Table 29. Elasticities of substitution per function group going out from the translog model for the weighted patient days.

elasticity of substitution	functiongroup: I	II	III	IV	total
Staff and Beds	-0,21	-0,22	-0,33	-0,53	-0,33
Staff and Spec.	0,00	0,05	0,00	-0,03	0,02
Staff and Fac.	-1,02	-0,89	-2,69	81,02	-2,11
Staff and Drugs	6,16	0,58	1,22	1,15	0,96
Beds and Spec.	0,00	0,05	0,00	-0,03	0,02
Beds and Fac.	0,39	0,45	0,46	0,53	0,49
Beds and Drugs	2,39	0,41	0,65	0,71	0,59
Spec. and Fac.	0,00	-0,02	0,00	-0,04	0,01
Spec. and Drugs	0,00	0,30	0,00	-0,02	0,04
Fac. and Drugs	0,65	0,75	9,14	-0,02	-9,24

For some elasticities of substitution only small differences per function group are to be noticed; for others the differences are greater. The elasticity of substitution between the staff and the number of beds is negative. This points to complementarity. In other words, with regard to the number of

weighted patient days, there was an attracting influence of the number of beds on the number of staff members (or the reverse) rather than of substitution. With the weighted admissions there is indeed substitution. There is also complementary rather than substitution between staff and facility index. This also holds for the facility index and drugs.
There are indications for substitution possibilities between the number of staff members and drugs and between beds and drugs and beds and the facility index. One can only draw conclusions, however, if the standard deviations and the distribution of the elasticities of substitution are also taken into account.
On the basis of the already mentioned analytical and simulation procecure (Appendix IV.7) it must be concluded from these - here not presented - figures, that accurate conclusions about the size of the elasticities of substitution concerning the separate staff categories. We have indications that the substitution possibilities are not great.

Scale effects

In IV.1 it was concluded on the basis of the Cobb-Douglas specification that there are significantly advantageous scale effects with regard to the weighted patient days. Table 30, on the basis of the translog model of the weighted patient days, gives the path of the scale effects and the related standard deviation per function group. The general conclusion is again that there are significantly advantageous scale effects.
The scale effects are indeed somewhat different between the function groups but these differences are not statistically significant. The same can be stated with regard to the path of the scale effects within a function group. The scale effects in larger hospitals are not significantly higher than in smaller hospitals.

IV.3.3. Estimation translog production functions for the intermediary production

Table 31 gives the results of the estimation of a translog production function for the intermediary production.
From the F-test on the null hypothesis that all quadratic and interaction terms are equal to 0, it can be deduced that with regard to the Cobb-Douglas specification the translog specification gives an improvement. The calculated F-value for the elimination of the cross terms and the quadratic terms is 1,51. This implies that at the 90% level, it can be concluded that the reduction of the translog model to the Cobb-Douglas model leads to information loss. A translog model was also tested with a further subdivision of staff into four categories (table 32). The calculated F-value of the elimination of the cross terms and the quadratic terms (Cobb-Douglas model) is 1,03. From this one can get no indication that the Cobb-Douglas

Table 30. Scale effects with the standard deviation per function group going out from the translog function for the weighted patient days.

Decrease/ increase inputlevels	function-group I Σ	σ_Σ	function-group II Σ	σ_Σ	function-group III Σ	σ_Σ	function-group IV Σ	σ_Σ
- 50%	1,09	0,11	1,14	0,10	1,12	0,07	1,14	0,06
- 45%	1,09	0,11	1,14	0,09	1,14	0,06	1,16	0,05
- 40%	1,08	0,10	1,13	0,08	1,13	0,05	1,16	0,05
- 35%	1,09	0,09	1,14	0,07	1,12	0,05	1,15	0,05
- 30%	1,09	0,08	1,13	0,07	1,13	0,04	1,17	0,05
- 25%	1,08	0,08	1,15	0,06	1,13	0,04	1,16	0,05
- 20%	1,09	0,07	1,15	0,06	1,14	0,04	1,16	0,05
- 15%	1,10	0,07	1,13	0,06	1,13	0,04	1,16	0,05
- 10%	1,10	0,060	1,13	0,05	1,13	0,04	1,17	0,06
- 5%	1,10	0,06	1,14	0,05	1,13	0,04	1,16	0,06
Average inputlevel	1,10	0,05	1,14	0,05	1,13	0,04	1,16	0,06
+ 5%	1,10	0,05	1,14	0,04	1,14	0,04	1,17	0,06
+ 10%	1,09	0,05	1,13	0,04	1,14	0,04	1,16	0,07
+ 15%	1,11	0,05	1,13	0,04	1,13	0,05	1,17	0,07
+ 20%	1,11	0,05	1,15	0,04	1,15	0,05	1,17	0,07
+ 25%	1,10	0,05	1,14	0,04	1,14	0,05	1,17	0,08
+ 30%	1,10	0,05	1,14	0,04	1,15	0,05	1,17	0,08
+ 35%	1,10	0,04	1,14	0,04	1,15	0,06	1,17	0,08
+ 40%	1,10	0,04	1,13	0,04	1,14	0,06	1,16	0,09
+ 45%	1,11	0,04	1,14	0,04	1,15	0,06	1,16	0,09
+ 50%	1,11	0,04	1,14	0,05	1,15	0,07	1,18	0,09

specification would, in regard to the translog specification, be too restricted.
A number of F-tests on the separate inputs (constant output elasticities) or on a combination of 2 inputs (elasticities of substitution equal to 1) show that the null hypothesis (Cobb-Douglas specification) must be rejected on a number of aspects. The calculated F-values of the quadratic and cross terms of the number of beds and drugs are respectively 2,02 and 2,12 with [5,86] degrees of freedom. F-tests on the quadratic terms and the cross term of 2 inputs give rejection of the null hypothesis at the 90% level, for virtually all combinations, with the exception of facility index-drugs and specialists-facility index.
The tests on the model with the 7 inputs also gives significant deviations from the Cogg-Douglas specification in several aspects.

Table 31. Translog production function for the intermediary production and 5 inputs.

Inputs		
C	15,26	(3,34)
Staff	0,528	(1,563)
Beds	0,176	(1,652)
Spec.	0,601	(0,861)
Fac.	0,640	(0,581)
Drugs	-0,901	(0,551)
$(\text{Staff})^2$	-0,707	(0,348)
$(\text{Beds})^2$	-0,960	(0,418)
$(\text{Spec.})^2$	0,126	(0,107)
$(\text{Fac.})^2$	0,0504	(0,0362)
$(\text{Drugs})^2$	0,0209	(0,0312)
Staff * Beds	1,425	(0,687)
Staff * Spec.	-0,0285	(0,2743)
Staff * Fac.	0,257	(0,147)
Staff * Drugs	-0,0755	(0,1701)
Beds * Spec.	0,247	(0,321)
Beds * Fac.	-0,392	(0,182)
Beds * Drugs	0,2598	(0,1603)
Spec. * Fac.	-0,0292	(0,0999)
Spec. * Drugs	-0,109	(0,0849)
Fac. * Drugs	0,0067	(0,0559)
R^2	0,989	
N	104	
$\bar{R}^2$	0,986	

Output elasticities and elasticities of substitution

Table 33 shows the output elasticities and elasticities of substitution of the model with 5 inputs and table 34 the same for the disaggregated model, at the average levels of the inputs.

The output elasticities of the number of beds, the staff, and drugs deviate significantly from 0. These outputelasticities are, respectively, 0,68 (σ = 0,06), 0,22 (σ = 0,06) and 0,15 (σ = 0,02). The Cobb-Douglas specification gives virtually the same elasticities (table 8). With regard to the elasticities of substitution it can be seen that a number of them are not equal to 1. We will return later to the significance of these differences.

From table 34 it can be concluded that the paramedical staff has a statistically significant output elasticity (0,25; σ = 0,09). The registered and student nursing staff are less relevant.

When we consider the output elasticities per function group we see that differences in input levels lead to differences in the output elasticities (table 35). This holds particularly for the staff, drugs and the number of specialists. The output elasticity of the staff is higher in function group I (0,30) than in function group IV (0,14).

Table 32. Translog model for the intermediary production and 7 inputs.

Inputs		
C	8,987	(4,197)
RN	-1,718	(2,056)
StN	-0,987	(1,369)
ON	0,222	(0,369)
PM	0,929	(0,888)
Beds	3,287	(3,348)
Spec.	-0,617	(1,432)
Fac.	0,0547	(0,838)
$(RN)^2$	-0,188	(0,208)
$(StN)^2$	-0,0373	(0,0533)
$(ON)^2$	0,0144	(0,0196)
$(PM)^2$	0,1315	(0,0727)
$(Beds)^2$	-0,673	(0,682)
$(Spec.)^2$	0,269	(0,147)
$(Fac.)^2$	0,0284	(0,0499)
RN * StN	-0,177	(0,342)
RN * ON	0,0244	(0,1207)
RN * PM	0,0683	(0,2174)
RN * Beds	0,889	(0,743)
RN * Spec.	-0,139	(0,299)
RN * Fac.	-0,322	(0,207)
StN * ON	-0,1301	(0,0929)
StN * PM	0,148	(0,216)
StN * Beds	0,407	(0,471)
StN * Spec.	-0,081	(0,266)
StN * Fac.	-0,0298	(0,0871)
ON * PM	0,0269	(0,0635)
ON * Beds	0,0264	(0,1403)
ON * Spec.	-0,0164	(0,721)
ON * Fac.	0,0246	(0,344)
PM * Beds	3,363	(0,317)
PM * Spec.	-0,265	(0,181)
PM * Fac.	0,0657	(0,1005)
Beds * Spec.	0,1079	(0,4917)
Beds * Fac.	0,114	(0,290)
Spec. * Fac.	0,121	(0,155)
R^2	0,985	
N	104	
$\bar{R}^2$	0,978	

Table 33. Elasticities of substitution and output elasticities of the translog model for the intermediary production and 5 inputs.

Inputs	output-elasticity		elasticity of substitution 1	2	3	4	5
Staff	0,22	(0,06)	.				
Beds	0,68	(0,06)	0,10	.			
Spec.	-0,02	(0,04)	0,06	0,06	.		
Fac.	0,02	(0,03)	-0,72	-0,19	0,01	.	
Drugs	0,15	(0,02)	0,33	0,52	0,07	-0,26	.

Table 34. Elasticities of substitution and output elasticities of the translog model for the intermediary production.

	output-elasticity		elasticity of substitution 1	2	3	4	5	6	7
RN	0,09	(0,08)	.						
StN	0,10	(0,07)	0,65	.					
ON	0,03	(0,02)	0,57	-0,70	.				
PM	0,25	(0,09)	0,25	0,47	2,47	.			
Beds	0,66	(0,12)	0,14	0,34	2,29	-101,72	.		
Spec.	-0,09	(0,06)	0,04	-0,02	-0,56	0,14	0,14	.	
Fac.	-0,03	(0,56)	-0,10	0,48	-0,05	0,28	0,25	0,56	.

Table 35. Output elasticities of the 5 inputs and the standard deviation per function group for the intermediary production.

	functiongroup									
	I		II		III		IV		total	
Inputs	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ
Staff	0,30	(0,09)	0,26	(0,08)	0,26	(0,07)	0,14	(0,12)	0,22	(0,06)
Beds	0,70	(0,09)	0,67	(0,07)	0,61	(0,08)	0,68	(0,12)	0,68	(0,06)
Spec.	-0,08	(0,06)	-0,08	(0,05)	0,04	(0,03)	0,08	(0,06)	-0,02	(0,04)
Fac.	0,01	(0,03)	0,03	(0,04)	0,01	(0,04)	0,01	(0,06)	0,02	(0,03)
Drugs	0,10	(0,03)	0,14	(0,02)	0,14	(0,03)	0,18	(0,04)	0,15	(0,02)

This implies that the staff, given the other inputs, has a stronger influence in function group I than in function group IV. The opposite goes for the specialists and drugs.
Table 36 shows the output elasticities of the 7 inputs per function group.

Table 36. Output elasticities of the 7 inputs and the standard deviation for the intermediary production per function group

	Functiongroup									
	I		II		III		IV		Total	
Inputs	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ
RN	0,21	(0,11)	0,12	(0,08)	0,09	(0,07)	0,10	(0,14)	0,10	(0,09)
StN	0,02	(0,09)	0,08	(0,08)	0,15	(0,06)	0,13	(0,09)	0,10	(0,07)
ON	0,04	(0,03)	0,03	(0,03)	0,02	(0,02)	0,05	(0,04)	0,03	(0,02)
PM	0,13	(0,08)	0,21	(0,08)	0,22	(0,09)	0,29	(0,12)	0,25	(0,09)
Beds	0,68	(0,15)	0,66	(0,11)	0,62	(0,10)	0,49	(0,20)	0,68	(0,13)
Spec.	-0,08	(0,09)	-0,10	(0,07)	-0,04	(0,05)	-0,03	(0,09)	-0,10	(0,07)
Fac.	0,01	(0,04)	-0,01	(0,05)	-0,03	(0,06)	-0,00	(0,09)	-0,04	(0,06)

The output elasticities of the different staff categories show different developments. The output elasticity of the registered nursing staff is higher in function group I (0,21; σ = 11) than in function group IV (0,10 = 0,14). We see the reverse for the student nursing staff and the paramedical staff. The output elasticity of the student nursing staff in function group I is 0,02 (σ = 0,09) and in function group IV is 0,13 (σ = 0,09). These figures for paramedical staff are, respectively, 0,13 (σ = 0,08) amd 0,29 (σ = 0,12). This implies that registered nursing staff is more relevant in function group I than in function group IV. The student nursing and paramedical staff are more relevant in function group IV than in function group I.

Appendices IV.9 and IV.10 show the path of some output elasticities and the standard deviation at different levels of the number of beds. In conclusion, a few more remarks about elasticities of substitution follow. Tables 33 and 34 gave the elasticities of substitution between the inputs with relation to the intermediary production. Most of the elasticities of substitution are smaller than 1; some are even negative. The approach for deducing the standard deviation and the distribution of the elasticities of substitution as are given in Appendix IV.7, are also applied to the production function of the intermediary production.
On the basis of these calculations, we get indications that the elasticities of substitution between the inputs are lower than 1. It is not possible to draw more exact conclusions about the size of the substitution possibilities.

Scale effects

Table 37 gives the scale effects per function group with relation to the intermediary production.

Table 37. Scale effects with standard deviations per function group going out from the translog function for the intermediary production.

	Function-group I		Function-group II		Function-group III		Function-group IV	
	Σ	σ_Σ	Σ	σ_Σ	Σ	σ_Σ	Σ	σ_Σ
- 50%	1,01	0,10	1,01	0,08	1,04	0,05	1,06	0,04
- 45%	1,01	0,09	1,01	0,07	1,04	0,04	1,06	0,03
- 40%	1,02	0,08	1,01	0,07	1,04	0,03	1,07	0,03
- 35%	1,02	0,07	1,01	0,06	1,04	0,03	1,07	0,03
- 30%	1,02	0,07	1,01	0,05	1,04	0,02	1,07	0,03
- 25%	1,02	0,06	1,01	0,05	1,05	0,02	1,07	0,03
- 20%	1,02	0,06	1,02	0,04	1,05	0,02	1,07	0,03
- 15%	1,02	0,05	1,02	0,04	1,05	0,02	1,07	0,04
- 10%	1,02	0,05	1,02	0,04	1,05	0,02	1,07	0,04
- 5%	1,02	0,04	1,02	0,03	1,05	0,03	1,07	0,04
Average inputlevel	1,02	0,04	1,02	0,03	1,05	0,03	1,07	0,05
+ 5%	1,02	0,04	1,02	0,03	1,05	0,03	1,08	0,05
+ 10%	1,02	0,04	1,02	0,03	1,05	0,04	1,08	0,06
+ 15%	1,02	0,03	1,02	0,02	1,05	0,04	1,08	0,06
+ 20%	1,03	0,03	1,02	0,02	1,05	0,04	1,08	0,06
+ 25%	1,03	0,03	1,02	0,02	1,05	0,05	1,08	0,07
+ 30%	1,03	0,03	1,02	0,02	1,05	0,05	1,08	0,07
+ 35%	1,03	0,03	1,02	0,03	1,05	0,05	1,08	0,07
+ 40%	1,03	0,03	1,02	0,03	1,06	0,05	1,08	0,07
+ 45%	1,03	0,03	1,02	0,03	1,06	0,06	1,08	0,08
+ 50%	1,03	0,03	1,03	0,03	1,06	0,06	1,08	0,08

The scale effects increase a little from function group I to function group IV but the differences are only significant to a slight degree. We also see scarcely any changes in the scale effects within each function group.
The general conclusion can be that, with respect to the intermediary production in the larger hospitals, there are slightly economics of scale.

IV.4. General conclusion about estimation of production functions

A number of different specifications of the production function have been estimated in the foregoing sections. This concerns the definitions of output and inputs as well as to the model specification.

We began with the estimation of a number of Cobb-Douglas production functions, taking as our starting point three output definitions: weighted admissions, weighted patient days and the intermediary production.

We then estimated a number of CES specifications. This function has some less stringent assumptions. With respect to the nonlinear character of this function, different methods of estimation were employed. None of the estimations gave results which, statistically speaking, reject the Cobb-Douglas specification.

Finally, the more general translog specification is estimated. This production function gives - depending on the output definition - results that differ statistically significant on a number of points from the Cobb-Douglas specification. However, going out from the available data, preference can not be given to the translog function with regard to all aspects of the production structure. This implies that a number of quadratic and cross terms can be eliminated from the model specification so that less parameters need to be estimated. This last is a problem with the translog specification; the number of parameters to be estimated increase quadratically with the number of inputs. This model reduction depends on the output definition. The possibilities of model reduction are greater with weighted patient days than with weighted admissions and the intermediary production.
Several model reductions were tested in this study but it is advisable to elaborate on one or another of them through further investigation.
A discussion of the results was taken up in Chapter I. Different model estimations were also compared with each other in this chapter.
We will make here some remarks. The number of beds is an input factor more relavant for the weighted patient days than for the weighted admissions. Although the beds are also of great importance for the weighted admissions, the weighted patient days are more coupled to the number of beds than are weighted admissions. This implies that the weighted patient days show us the output heterogeneity between hospitals in lesser degree than the weighted admissions. This can be illustrated in the light of the variation coefficient of the weighted admissions/admissions (20%) and the weighted patient days/patient days (8%). The differences in the weighted admissions admissions are more than two times as great as in the weighted patient days/patient days. The variation coefficients of the number of admissions and the number of patient days are nearly equal to each other, as are those of the weighted admissions and the weighted patient days. The weighing mechanism

in the admissions thus represents more differentiations in the output than the weighing mechanism in the patient days. The results of the intermediary production look more like those of the weighted admissions than those of the weighted patient days. There are indeed several differences, however. In the same way, the paramedical staff is more relevant for the intermediary production than for the weighted admissions. This is especially because the medical treatments work directly in the intermediary production and indirectly in the weighted admissions.
In Chapter III the allocation process in the hospital sector was described. Production (patient days, medical treatments, outpatient activities, etc.) takes place on behalf of the patient care and the training functions.
In Chapter II it was noted that Baron makes a distinction between a production function (relationship between intermediary production and inputs) and a treatment function (relationship between the weighted admissions and the intermediary production). To test these relationships, we estimate the following simultaneous model (recursive):

Intermediary production (IP) = f (inputs) (1)
Weighted admissions WADM = g (intermediary production) (2)

The first equation is the production function as it is dealt with in the foregoing. The second equation (in double logarithmic specification) looks like the treatment function of Baron.

$$\ln \text{WADM} = \underset{(0{,}0253)}{0{,}972} \ln \widehat{\text{IP}} + \underset{(0{,}408)}{0{,}461} \qquad (R^2 = 0{,}94)$$

These estimates imply that an increase in IP of 1% is related to an increase in the weighted admissions of 0,97%.
The $R^2 = 0{,}94$, which implies an extremely high relationship between the differences in the weighted admissions and the differences in the intermediary production. Thus, from the viewpoint of the weighted admissions, there are systematic relations in the production of patient days, treatments, etc. (see also scheme chapter III, page 60). The systematic relationships between the function groups on the one hand and in the other, a large number of patient characteristics the production on the treatment departments were already pointed out in Chapter I.
Two production models were also estimated in which particularly the assumption that drugs are exogenous with relation to the output was abandoned (Appendix III.1). Going out from the Cobb-Douglas specification, this gives, for the ultimate production function, no deviating estimates.

Chapter V: Performance indices for general hospitals

V.1. Introduction

In this chapter will be given a number of possibilities for implementation, in the framework of an evaluation of several aspects of the functioning of a hospital, of the models drawn up in our investigation.
Cost functions such as those described by van Aert (1977) will be considered as well as our production functions.
With this evaluation, the character of the analysis must be taken into account. Our models are based on a comparison of hospitals in a particular year (inter-hospital comparison).
As was already said in Chapter I, the estimated functions have a "behavioural" or "average" character. They represent the average functioning of hospitals. This implies that one can deal with the models as an instrument for inter-hospital comparison ("mirror" function).
Among others van Mansvelt (1978), Griffith (1978) and Groot (1979) have shown the importance of the firm comparison with respect to stimulating the efficiency of the hospital sector.
In V.2. we will define a number of performance indices and give their theoretical background. In V.3. these indices will be calculated on the basis of the estimated models.

V.2. Cost index, output index and input index

Cost index

On the basis of the cost function a cost index per hospital can be calculated.[1)]
This index is based on the ratio between the observed costs (OK_i) of hospital i and the expected costs of hospital i ($\widehat{EK}_i$).
The expected costs are calculated on the basis of, on the one hand, the estimated parameters of the stated variables in the cost model and, on the other hand, the observed value of the stated variables for hospital i. The cost index (C_i) is defined as follows:

$$\hat{C}_i = \frac{OK_i}{\widehat{EK}_i}$$

The meaning of the cost index is as follows:

$\hat{C}_i = 1$: means that hospital i with relation to the cost level has functioned in accordance with the sector average;
$\hat{C}_i < 1$: means that hospital i has functioned with relatively lower costs than according to the sector average;
$\hat{C}_i > 1$: means that hospital i has functioned with relatively higher costs than according to the sector average.

---

1) van Aert et al. (1976), van Aert (1977), Feldstein (1965 and 1967b), Feldstein and Schuttinga (1977).

With the interpretation of the cost indices it must be noted that the differences therein have no connection anymore with factors taken up in the cost model such as the function of the hospital (specialization, training function, % ENT patients, facilities, outpatient variable), its size, occupancy rate, length of stay, year of construction, etc. The differences in the cost indices can be connected, however, with factors outside our analysis such as differences in quality of care (inasmuch as not taken up implicitly) and differences in efficiency. Neither does the model take any account of factors specific only to a single hospital. (van Aert et al., 1977b).
Such indices can be calculated in an analogous manner for separate staff and cost categories.

Output index

The expected output of a hospital, given its set of inputs, can be determined with the aid of the production function. The "productivity" - in terms of utilization of inputs - of a hospital i is measured as the ratio of the observed output (Q_i) and the expected output of hospital i ($\hat{Q}_i$). The expected output of hospital i is determined, on the one hand, on the basis of the average production function and, on the other hand, the observed inputs of hospital i.

$$\hat{O}_i = \frac{Q_i}{\hat{Q}_i}$$

where: $\hat{O}_i$ = the output index of hospital i

Q_i = the observed output of hospital i

$\hat{Q}_i$ = the expected output of hospital i on the basis of the estimated production function and the given set of inputs of hospital i.

Feldstein (1967b) and Berki (1972) interpret the output index as a productivity index. Seeing the fact that in our analysis - just as in that of Feldstein - it is not the "outcome" of health care that is measured but health care itself, then the term "productivity" must be interpreted in a limited sense and therefore we prefer the term output index. (see also Cochrane, 1972). Given the output definition, the difference in utilization of the inputs is indicated.

Relation between cost index and output index: input index

Marschalk and Andrews Jr. (1944) have introduced the notions of technical and economic efficiency. Farrell (1957) postulated that as one talks about the efficiency of an enterprise, one mostly alludes to the measure to which the enterprise strives to produce the greatest possible output for a given set of inputs. This is related to a certain degree with the notion of technical efficiency. Next to it Farell introduces the notions of price efficiency and overall efficiency. He takes technical efficiency to mean the difference between the observed output and the expected output, which is determined on the basis of the production function and the set of inputs.

Thus, this means that technical efficiency is measured by means of the error term of the production function. By economic efficiency is understood the extent to which one succeeds to select the most "lucrative" combination of inputs for a certain output, concerning quantities as well as prices of the inputs. Farrell takes as his starting point the efficient production function and constant returns to scale. By this is meant the production function, that gives the expected output, which a "perfect" efficient enterprise can realize for a given combination of the inputs. Farrell defines further that the overall efficiency = price efficiency x technical efficiency. Feldstein (1967b) has applied Farrell's framework to the hospital sector. He indicates the overall efficiency through his cost index. Technical efficiency is called productivity but the content of the two notions is identical. He terms price efficiency as input efficiency, for the reason that the prices of the inputs for all (English) hospitals are uniform.
An essential difference in the approaches of Feldstein and Farrell is that Farrell takes the "best practice" or "efficient" production function as his starting point and Feldstein the "average" production function.
We will now, as Feldstein did, go further into the significance of the three indices:

(a) the cost index (C)
(b) the output index (O)
(c) the input index (I)

As is said before we give a more limited meaning to the indices. We do not interpret directly in terms of efficiency but as performance indices which can play a role in interhospital comparison. In that way it can get an efficiency meaning.
It is possible, according to Feldstein, to find a plausible basis by which to analyse differences in the cost index and differences in the output index and the input index. Figure 8 illustrates the relation between the indices.
Our starting point is 2 inputs, X_1 and X_2, and one output Q. The curve "production function 1" is the production function of the "average" hospital. This enables the combination of X_1 and X_2 to produce output Q_o. Going out from a Cobb-Douglas specification:

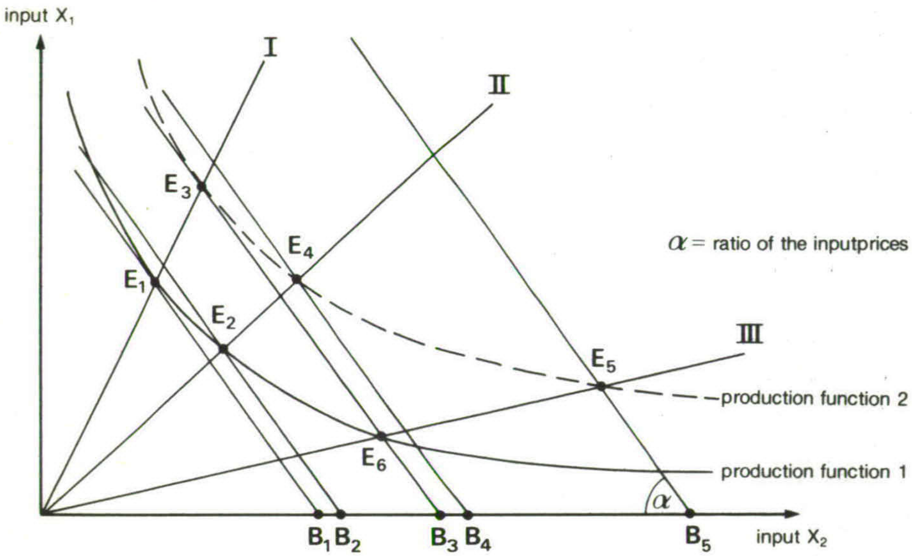
$$Q_o = A \cdot X_1^{\alpha_1} \cdot X_2^{\alpha_2}$$

"Production function 2" is the production function of a certain hospital i, given the input combinations with which one can produce output Q_o. Thus:

$$Q_{oi} = A \cdot X_{1i}^{\alpha_1} \cdot X_{2i}^{\alpha_2} \cdot \varepsilon_i$$

The production function of hospital i has a lower "productivity" than the "average" hospital. It is assumed that the "productivity" differences have a neutral character, which implies that α_1 and α_2 are the same for each hospital and that the scale effects are constant. So the two curves are parallel to each other. This has the consequence that the residual term $\varepsilon_i < 1$.

Grafic 8: Relation costindex, outputindex and inputindex



ε is equal to 1 for the "average" hospital.
The parallel lines B_1 through B_5 represent the iso-cost lines. The tangent of the angle of inclination is the price ratio of X_1 and X_2.
From the figure it can be deduced that the "average" hospital can produce Q_o most cheaply with the input combinations represented through point E_1. But the "average" hospital need not be completely efficient in its choice of the inputs and thus, for this reason, produce with another input ratio, e.g. point E_2 on II. If hospital i produces according to this input ratio it is then situated at point E_4. The "average" hospital can produce according to a worse input ratio than II, e.g. E_6. If hospital i produces according to this input ratio, it is then situated at point E_5 on III.
If we now start with hospital i and production level Q_o at production point E_5, we can state the following:

$C = B_5/B_2$, the cost index hospital i (observed costs/expected costs).

We must take E_2 as comparison point because the "average" hospital is not perfectly efficient in its choice of inputs, but produces according to E_2. The "average" hospital is, namely, the reference point in our analysis. ("mirror").
As mentioned above, "productivity" is defined as the ratio of the observed output and the expected output on the basis of the "average", with a given set of inputs. If we begin with constant scale effects, a proportional increase in the distance of the origin along one of the lines representing the input ratios will then correspond with an equal proportional increase in the hospital output. This means, then, that if the

"average" hospital allocates the inputs according to E_5, its output will then be higher than that of hospital i and be equal to:

$$\frac{E_5O}{E_6O} \cdot Q_o$$

The "productivity" of hospital i is then equal to the ratio of Q_o and $\frac{E_5O}{E_6O} \cdot Q_o$, thus:

$$O_i = \frac{E_6O}{E_5O}$$

or, because of the fact that the production functions are parallel:

$$O_i = \frac{E_2O}{E_4O} = \frac{B_2}{B_4}$$

The quotient of C_i and O_i is called the input efficiency by Feldstein and is thus $\frac{B_4}{B_5}$.

Thus:

$$\frac{B_5}{B_2} = \frac{B_5}{B_4} \cdot \frac{B_4}{B_2}$$

$$C_i = \frac{B_5}{B_2}, \quad O_i = \frac{B_2}{B_4} \quad \text{and} \quad I_i = \frac{B_4}{B_5}$$

$$C_i = I_i^{-1} \cdot O_i^{-1}$$

$$C_i = \frac{1}{O_i \cdot I_i}$$

The output index concerns the shifting of one curve towards the other, while the input index concerns the shifts along a particular curve.

V.3. Application of the performance indices for general hospitals

In this section we will make calculations with the above defined indices. For the output index we use the translog specification of the production function (Chapter IV). It can be seen that the Cobb-Douglas specification leads to virtually the same indices. The correlation of the output index for the weighted admissions going out from the translog specification (see table 14) and the output index going out from the Cobb-Douglas specification is 0,98.
It will be noted that the estimated standard deviation of the expected output on the basis of the translog model is,

generally speaking, somewhat higher than on the basis of the Cobb-Douglas model.
For the cost indices, we start with the model of the costs per admission, as specified in van Aert (1977). Taken up in this model, as we said in Chapter I, are, among other things, the (adjusted) length of stay and the occupancy rate. In the light of the significance of the different indices, with respect to the interhospital comparison, it may be asked if these variables must be included in the cost index. If, for example, one includes the length of stay in the cost index, this implies that the variation in the length of stay carries through into the input index. Considering the significance of the input index, this is not immediately self-evident. Therefore it is reasonable to eliminate the length of stay from the cost model so that the cost index determines this variable too. Doing so has the consequence, again, that differences in length of stay do not carry through into the input index. Occupancy rate and any other factors may also be considered in the same manner.
Table 38 gives the frequency distribution of the cost index (of the costs per admission exclusive of length of stay), the output index for the weighted admissions and the input index that can be calculated from them.

Table 38: Frequency distribution of the cost index, output index and input index (weighted admissions).

	cost index		output index		input index	
	N	%	N	%	N	%
index ≤ 0,85	19	18,4	11	10,5	9	8,7
0,85 < index ≤ 0,90	13	12,6	18	17,1	11	10,7
0,90 < index ≤ 0,95	16	15,5	9	8,6	13	12,6
0,95 < index ≤ 1,00	12	11,7	17	16,2	14	13,6
1,00 < index ≤ 1,05	1	10,7	20	19,0	13	12,6
1,05 < index ≤ 1,10	6	5,8	9	8,5	14	13,6
1,10 < index ≤ 1,15	9	8,7	3	2,9	13	12,6
index > 1,15	17	16,5	18	17,1	16	15,5
totaal	103	100	105	100	103	100

The relationship between the indices are represented in the graphics 6,7 and 8, from which it can be concluded that the relationship between the cost index and the output index (ρ = -0,61) is quite strong, as is the relationship between the cost index and the input index (ρ = -0,56). The correlation between the output index and the input index is notably lower (ρ = -0,20). Feldstein found comparable results; reaching his conclusions, from the difference in decision-makers regarding the output and input indices. With regard to the output index (utilization of the given inputs), this is especially the case for the medical and nursing staff. The input index is determined much more by the (financial and economic) management at hospital level, the regional situation, allocation decisions taken in the past, and so forth.
Berki (1972) found that this difference can also be reversed.

Possibly the management at hospital level is especially interested in productivity while the medical staff wants new facilities procured. Berki nevertheless holds that the indices are a meaningful analytical tool, but that further investigation is desirable, especially also in the light of the object function of a hospital. The interpretation of the indices depends on the way in which one considers the hospital process. Quantitative analysis can be clarifying this discussion.
Berry (1974), on the basis of the residuals of a regression model for the explanation of the differences in costs among hospitals, has selected a number of hospitals with relatively low and relatively high costs and studied them in furher detail. This is in fact a selection made on the basis of the cost index of Feldstein. A study of extreme hospitals (relative high or low costs) can, as Berry says, offer information for adjusting the model, but also give notions for adjusting the hospital policy.
Grimes and Moseley (1976), via an entirely different approach, come to the conclusion that there is indeed a reasonably high relationship between the "effectivity" with respect to patient care and that with respect to the administrative and organizational aspects of the hospital functioning. They have developed a more direct approach, based on "expert opinion", for the measurement of effectivity.
Groot (1978) also wonders whether a quite stringent separation in the decisions is possible.

In the following we will, through relating the indices to a number of factors concerning hospital functioning, pursue their possibilities in the framework of the inter-hospital comparison. The indices can be seen as a "mirror" in which the individual hospital can see themselves reflected (see also van Aert and van Montfort, 1980).
Discussions about the differences in the indices of hospitals, can give policy indications for the management of a hospital. This is especially important for the hospitals because market incentives for efficiency are lacking because of the elimination of the market-mechanism (Groot, 1972). The interhospital comparison offers the opportunity to use the experiences of other hospitals. Shortell et al. (1975) has done an investigation in the USA into the meaning of the availability of figures of other hospitals for the costs of a hospital. He concluded that the availability and use of comparative figures lowers the costs.
It should be recalled that a detailed interpretation of the indices is already given in Chapter I. Here, the focus will be on presenting a number of numerical data.

Table 39 shows the averages per function group for several indices.

Table 39: Indices, length of stay variables and production of treatment-departments per function group.

Function group	I	II	III	IV	to-tal
1. Output index weighted admissions	1,00	1,00	1,02	1,03	1,01
2. Output index interm. production	0,98	1,01	1,01	1,00	1,00
3. Output index weighted patient days	1,01	0,99	1,01	1,02	1,00
4. Cost index (incl. length of stay)	1,00	1,01	0,99	1,00	1,00
5. Cost index (excl. length of stay)	0,96	0,98	1,00	1,05	1,00
6. Input index weighted admissions	1,06	1,05	1,02	0,94	1,03
7. Adjusted length of stay	18,2	18,0	18,9	18,9	18,5
8. Obs. length of stay	15,8	16,1	17,4	17,3	16,6
9. Expected length of stay	15,9	17,0	17,6	18,5	17,4
10. |Obs. -expected| length of stay	-0,1	-0,9	-0,2	-1,2	-0,8
11. Specialism-dispersal index	92,0	92,4	98,7	105,8	97,6
12. Diagnosis-dispersal index	90,3	97,5	98,8	102,3	98,3
13. Operation-dispersal index	86,9	95,5	102,6	111,3	100,7
14. % Pats. needing 2 or more doctors	12,3	13,2	17,8	20,9	16,6
15. Degree of despecialization	98,1	88,9	76,8	61,8	82,1
16. % ENT patients	18,6	15,0	12,7	10,1	13,9
17. Specialist training	0	0,1	0,4	1,0	0,3
18. Operation I-III per 100 adm.	11,6	15,4	17,8	23,1	16,1
19. X-ray tests per adm.	301,8	313,5	394,7	467,4	359,0
20. Physioth. treatm. per adm.	436,2	484,7	490,6	565,0	487,1
21. Funct. invest. "heart" per 100 adm.	72,6	75,3	75,2	109,4	78,8
22. Funct. invest. "brain" per 100 adm.	10,3	17,6	24,0	23,8	19,1
23. Radioact. isotherap. per 100 adm.	0	1,9	2,6	13,3	2,9
24. Laboratory tests per 100 adm.	60,7	87,0	124,5	158,9	104,6

The output indices of the respective output measurements (row 1,2 and 3) show no relation with the function groups. This means that the differences in output among the function groups in these output definitions have been included well.
That there are great differences in output among the function groups may become evident from other data in table 39 . The data on row 11 through 17 concern a number of patient characteristics and the training program. The specialisms-dispersal index, the diagnosis-dispersal index and the operation-dispersal index are based on frequency of occurrence.
From function group I to function group IV, these indices increase. The less frequently occurring specialisms, diagnoses and operations are thus more strongly represented in function group IV hospitals than in hospitals in function group I.
With regard to the percentage of ENT patients (children with adenoids or tonsilitis) the reverse can be observed. The hospitals in function group IV have, averagely, a more extensive training program than the hospitals in function group I.

That the hospitals in group IV have a more complex function than those in group I also appears from the higher production per 100 admissions, in the treatment departments.
An important indicator of the "weight" of the type of patients is the expected length of stay. This is based on the composition of the patient population in regard to diagnosis, age, sex, need or not for an operation, need or not for treatment by two or more doctors. The expected length of stay in function group IV hospitals is 2,6 days longer than in hospitals in function group I. This is also an indication of the more complicated patient population in the hospitals of function group IV. There is no systematic relationship with function groups in the difference between the observed and the expected length of stay. As far as the difference between the observed and the expected length of stay can be seen as an efficiency-indicator, we can conclude that - averagely - there are no efficiency differences between the hospitals in the different function groups. In table 40 there are a number of correlation coefficients between, on the one hand, the output indices of the weighted admissions resp. the intermediary production and, on the other hand, a great number of variables. These correlations confirm the results as they have been represented above.
The table points out the high correlation between the output indices with several length-of-stay variables and the occupancy-rate. In Chapter I we paid a lot of attention to the significance of these relationships. Here we will draw some attention on the variable "%65+". This is the percentage of admitted patients over 65 years old. The correlation between this variable and the output index of the weighted admissions is -0,50. The correlation with the output index of the intermediary production is considerable lower (-0,27). The relatively high correlation with the output index of the weighted admissions give indications to a certain extent for an "exogenous" character of the length of stay. For, however the correlations with the length of stay are relatively high. The correlation of the expected length of stay with the output index of the weighted admissions is very low. Since the expected length of stay not only depends on the age of the patients but also on the diagnosis, and so on, the difference between the observed and the expected lenght of stay has a meaning in terms of the efficiency in which the inputs are used.

Table 40: Correlations between output indices of weighted admissions resp. intermediary production and a number of variables.

variable	output index: WADM	interm. prod.
number of beds	0,00	0,03
spec. training	0,25	0,17
facility index	0,00	0,03
year of construction	0,16	0,03
% ENT patients	-0,11	-0,02
ownership	0,00	-0,10
lenghth of stay	-0,40	-0,09
adjusted lenght of stay	-0,70	-0,10
occupancy rate	0,38	0,45
N = 105		

continuation table 40

variable	output index: WADM	interm. prod.
expected length of stay	-0,12	-0,09
[observed- expected] stay	-0,54	-0,25
% 65+	-0,50	-0,27
operation index	,30	,18
clinic admission pressure	,19	,06
% emergency patients	,04	,15
% patient deaths	-0,37	-0,07
N = 41		

continuation table 40

variable	output index WADM	interm. prod.	N
operations	-0,05	-0,12	83
X-ray diagnosis	-0,12	-0,06	100
physiotherapy	-0,12	-0,07	81
function investment "heart"	-0,06	-0,19	97
function investment "brain"	-0,02	-0,01	68
radioactive isotherapy (≠ 0)	-0,06	-0,02	19
radioactive isotherapy (included 0)	-0,04	,06	98
laboratory points	-0,05	,07	83

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APPENDIX I.1

List of definitions of some variables

Adjusted length of stay (ALOS): $\frac{\text{(patientdays - ENT-patientdays)}}{\text{(admissions - ENT-admissions)}}$

Admissionindex (ADMIN): the admission index of hospital i is the sum of the admission coefficients of the municipalities, weighted by the percentage of patients of hospital i coming from each municipality.

Beds (Bed.): average number of available beds during a year.

Character (Char.): variable is 1 if the hospital has a fixed medical staff and becomes 0 if any medical specialist can work in the hospital at any moment.

Clerkship-training (Cler.tr.): dummy-variable is 1 if the hospital has a programme for clerkship-training and is 0 if the hospital does not.

Degree of despecialisation (Dsgr.): this is the number of admissions in the basic specialisms internal medicine and surgery as percentage of the admissions in all internal and surgical specialisms.

Degree of urbanisation (Urb.): a classification of the population-density of the town where the hospital has its residence.

Drugs (Drugs): costs for drugs (accouting-scheme-numbers: 46 "drugs and dressings" (DD); "other (para-)medical means" (PMM).

Ent-patients (ENT.): number of admissions in the specialism "ear, nose and throat" as percentage of the total number of admissions.

Facility-index (FAC.): this is the index based on a scale-analysis of the facilities (see Van Aert en Van Montfort, 1976).

Intermediary production (INTPROD.): the summation of the number of patientdays and the number of treatments weighted by the national tariffs.

Lenght of stay (LOS): number of patientdays/number of admissions.

Nursing-aid training (NAID.tr.): dummy-variable is 1 if the hospital has a programme for nursing-aid training and is 0 if the hospital has not.

Occupancy-rate (Occ.): $\frac{\text{(number of patientdays} \ast \text{100)}}{\text{(beds} \ast \text{365)}}$

Outpatient variable (Outp.): revenues of treatments for outpatient patients as a percentage of the revenues of all treatments.

Ownership (Own.): this variable becomes 1 for a private hospital, and 2 for a public hospital.

Specialists (Spec.): the number of medical staffmembers working in a hospital (not converted to number on full-time basis)

Specialist training (Spec.tr.): dummy-variable is 1 if the hospital has a training-programme for one or more specialisms and is 0 if the hospital does not have a training-programme for medical specialists.

Staff (Staff): average number of (nursing and paramedical) staffmembers, working in a hospital during a year, converted to a full-time basis. Conform the NZI-accountingscheme (Nationaal Ziekenhuisinstituut, 1968) this concerns the following categories: registered nurses (RN) 412; student nurses (StN) 413; other nursing staff (ON) 414; paramedical staff (PM) 415.

Type (Type): this variable becomes 1 if the hospital has a roman-catholic signature and 0 if the hospital has another religious signature or none.

Weighted admissions (WADM.): number of admissions (ADM), corrected conform the formula on page 66.

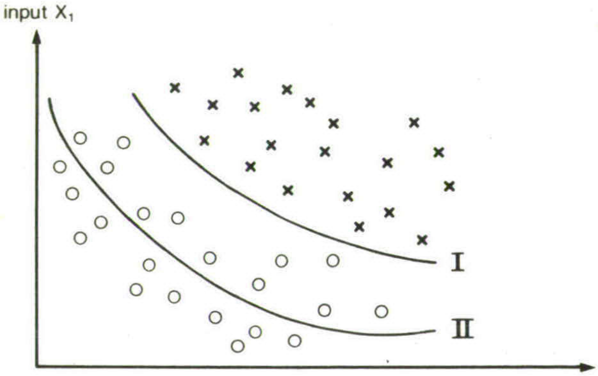
Weighted patientdays (WPAT.): number of patientdays, (PD), corrected conform the formula on page 68.

APPENDIX I.2

Estimation of a "more efficient" production function

In Chapter IV a number of production functions are estimated based on a cross-section of over a 100 hospitals. These production functions give a description of the average behaviour. We do not get information of the most efficient production function, the estimation of which is very difficult. One aspect of this problem is that for several reasons the efficiency level of the hospitals differ (see Chapter I). The residuals of the (average) production function gives the possibility of ranking the hospitals. The hospitals with a positive residual have, given the input levels a higher output level then is expected conform the model (fitted value). The hospitals with a negative residual have, given the input levels, a lower output level than is expected conform the model. We select the "more efficient" hospitals and estimate a new model.
In grafic 9 we illustrate the procedure grafically.

Grafic 9: Estimation procedure "more efficient" production function



Line I is the production function based on all hospitals. The ✱-hospitals have a negative residual on this production function, and the 0-hospitals have a positive residual. Line II is the production function based on the "more efficient" hospitals (0-hospitals). Table 41 gives the results of the regression analysis of the 50 "more efficient" hospitals.
From the relation between on the one side Beds and Staff and the output (Q) on the other side, the two models are compared.
The partial models are:
107 hospitals (see IV .3.1.):

$$\ln Q = -10,705 + 0,187 \ln \text{Staff} + 8,305 \ln \text{Beds} +$$

$$- 0,171 (\ln \text{Staff})^2 - 0,835 (\ln \text{Beds})^2 + 0,348 \ln \text{Staff}.\ln \text{Beds}.$$

Table 41: Translog production function of the weighted admissions and 5 inputs (50 more efficient hospitals).

Inputs	$\hat{\beta}$	$\hat{\sigma}$
Constant	10,941	7,861
Staff	-0,369	3,969
Beds	-0,244	4,426
Specialists	1,043	2,329
Drugs	0,323	1,124
Fac. index	0,019	1,808
$Staff^2$	0,461	1,007
$Beds^2$	0,589	1,123
$Spec.^2$	-0,113	0,234
$Fac.^2$	-0,035	0,062
$Drugs^2$	-0,071	0,109
Staff * Beds	-1,467	1,766
Staff * Spec.	0,127	0,699
Staff * Drugs	0,237	0,424
Staff * Fac.	0,165	0,409
Beds * Spec.	0,617	0,779
Beds * Drugs	0,041	0,431
Beds * Fac.	-0,129	0,480
Spec. * Fac.	-0,297	0,205
Spec. * Drugs	-0,181	0,276
Fac. * Drugs	0,038	0,116
R^2	0,982	
N	50	
$\bar{R}^2$	0,969	

50 hospitals:

$$\ln Q = -2{,}294 + 3{,}611 \ln \text{Staff} + 2{,}049 \ln \text{Beds} +$$

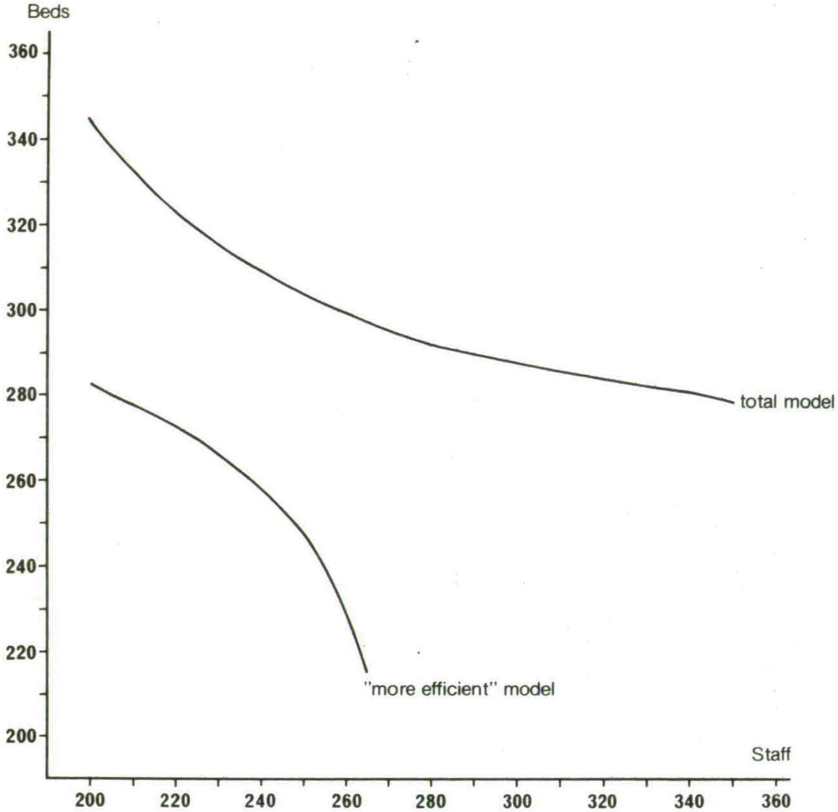
$$+ 0{,}461 (\ln \text{Staff})^2 + 0{,}589 (\ln \text{Beds})^2 - 1{,}467 \ln \text{Staff}.\ln \text{Beds}.$$

The constants in these partial models are calculated at the average levels of the output and the inputs.
In grafic 10 we present the two partial model grafically, within the empirical range of the staff and the number of beds.

The curve of the "more efficient" model is over the whole range below the curve of the total model.
At every level of the number of staff-members the same output can be produced with less number of beds, looking at the "more efficient" line.

The difference between the two models can be illustrated in an other way. We calculate the expected output level, given the average input levels, for the two models. The expected output level ($e^{\hat{q}}$) with "more efficient" model is 11.476.300 and with the total model 10.131.400.

Grafic 10: Relation of staff and beds on the average level of Q for the total resp. the "more efficient" model



This implies that the output level of the "more efficient" model is 13,3% higher than the output level of the total model. We remark that the "more efficient" model is not an exception but refers to half of the hospitals.
It seems relevant to compare the "efficient" and the "in-efficient" hospitals in more detail. Then we get possibly more insight in several factors within a hospitals and the behaviour of the specialists in the two groups of hospitals.

APPENDIX II.1

Derivation elasticity of substitution of the translog production function.

In this appendix the mathematical derivation of the elasticity of substitution between two inputs based on the translog production function specification is given.
In the first part we suppose specific input levels (η_i) and in the second part arbitrary input levels are supposed.

A. Elasticity of substitution between input j and k (e_{jk}) for specific input levels (η_i).

The following productionfunction is supposed:

$$q = \alpha_o + \sum_i \alpha_i . x_i + \sum_{\substack{i,l \\ i \leq l}} \beta_{ij} . x_i . x_l \tag{1}$$

where: $q = \ln \left(\frac{Q}{\eta}\right)$

Q = output level of a hospital

$x_i = \ln \left(\frac{X_i}{\eta_i}\right)$

X_i = level of input i of a hospital

$i = 1, \ldots, p$; p is the number of inputs and where η, η_i ($i = 1, \ldots, p$) are fixed output and input levels.

Further we define (Plasmans, 1971):

$$\left.\begin{aligned} R_{jk} &= \left(\frac{\partial Q}{\partial X_k}\right) / \left(\frac{\partial Q}{\partial X_j}\right) \; ; \; r_{jk} = \ln R_{jk} \\ V_{jk} &= (X_j / X_k) \; ; \; v_{jk} = \ln V_{jk} \\ e_{jk} &= \frac{\partial \ln V_{jk}}{\partial \ln R_{jk}} \; ; \; \text{elasticity of substitution between input j and k.} \end{aligned}\right\} \tag{2}$$

R_{jk} is the marginal rate of substitution of input k for input j, if Q and the other inputs are kept constant.
V_{jk} is the ratio of input j and k.

We consider V_{jk} as a function of R_{jk}, by varying in equation (1) the input level X_j and X_k and holding constant the other input levels and the output level Q.
From (2) follows:

$$R_{jk} = \frac{X_j}{X_k} \left(\frac{X_k}{Q} \cdot \frac{\partial Q}{\partial X_k}\right) / \left(\frac{X_j}{Q} \cdot \frac{\partial Q}{\partial X_j}\right) \tag{3}$$

So:

$$r_{jk} = v_{jk} + \ln \left[\frac{\partial q}{\partial x_k}\right] - \ln \left[\frac{\partial q}{\partial x_j}\right] \tag{4}$$

The goal is the derivation of e_{jk} based on (1) in the point $x_1 = 0$, $x_2 = 0$, ..., $x_p = 0$ (inputlevels $X_i = \eta_i$), so:

$$e_{jk} = \frac{\partial v_{jk}}{\partial r_{jk}} = 1 / \left(\frac{\partial r_{jk}}{\partial v_{jk}}\right) \tag{5}$$

This is the inverse of the partial differential of r_{jk} with respect to v_{jk}, while q and x_i, $i \neq j$ and $i \neq k$, are kept constant.
To begin with we derive v_{jk} and r_{jk} from (1):

$$v_{jk} = \ln\,(V_{jk}) = \ln\,(^{X_j}/X_k) = \ln X_j - \ln X_k = x_j - x_k + c \qquad (6)$$

$c = (\ln \eta_j - \ln \eta_k)$.

$$\text{Then: } \frac{\partial v_{jk}}{\partial v_{jk}} = \frac{\partial x_j}{\partial v_{jk}} - \frac{\partial x_k}{\partial v_{jk}} = 1 \qquad (7)$$

The partial derivative of (1) with respect to v_{jk} is:

$$\frac{\partial q}{\partial v_{jk}} = \alpha_j \cdot \frac{\partial x_j}{\partial v_{jk}} + \alpha_k \cdot \frac{\partial x_k}{\partial v_{jk}} + \sum_{i=1}^{j} \beta_{ij} \cdot x_i \cdot \frac{\partial x_j}{\partial v_{jk}} +$$

$$+ \sum_{i=1}^{k} \beta_{ik} \cdot x_i \cdot \frac{\partial x_k}{\partial v_{jk}} + \sum_{i=j}^{p} \beta_{ji} \cdot x_i \cdot \frac{\partial x_j}{\partial v_{jk}} +$$

$$+ \sum_{i=k}^{p} \beta_{ki} \cdot x_i \cdot \frac{\partial x_k}{\partial v_{jk}} = 0 \qquad (8)$$

(8) equals 0 because q is kept constant
In the point $x_i = 0$ ($i = 1, \ldots p$), (8) becomes:

$$\alpha_j \cdot \frac{\partial x_j}{\partial v_{jk}} + \alpha_k \cdot \frac{\partial x_k}{\partial v_{jk}} = 0 \qquad (9)$$

From (7) and (9) we can solve $\frac{\partial x_j}{\partial v_{jk}}$ and $\frac{\partial x_k}{\partial v_{jk}}$ in the point $x_i = 0$:

$$\alpha_j \cdot \left(1 + \frac{\partial x_k}{\partial v_{jk}}\right) + \alpha_k \cdot \frac{\partial x_k}{\partial v_{jk}} = 0$$

From this it follows:

$$\frac{\partial x_k}{\partial v_{jk}} = \frac{-\alpha_j}{\alpha_j + \alpha_k} \text{ and } \frac{\partial x_j}{\partial v_{jk}} = \frac{\alpha_j + \alpha_k - \alpha_j}{\alpha_j + \alpha_k} = \frac{\alpha_k}{\alpha_j + \alpha_k} \qquad (10)$$

Based on (1) we get:

$$\frac{\partial q}{\partial x_j} = \alpha_j + 2 \cdot \beta_{jj} \cdot x_j + \sum_{\substack{i=1 \\ i \neq j}}^{p} \beta_{ij} \cdot x_i \text{ and } \frac{\partial q}{\partial x_k} = \alpha_k +$$

$$+ 2\beta_{kk} \cdot x_k + \sum_{\substack{i=1 \\ i \neq k}}^{p} \beta_{ik} \cdot x_i \qquad (11)$$

From (4) and (11) it follows that:

$$r_{jk} = - \ln (\alpha_j + 2\beta_{jj} \cdot x_j + \sum_{\substack{i=1 \\ i \neq j}}^{p} \beta_{ij} \cdot x_i) + \ln (\alpha_k +$$

$$+ 2\beta_{kk} \cdot x_k + \sum_{\substack{i=1 \\ i \neq k}}^{p} \beta_{ik} \cdot x_i) + v_{jk}$$

$$\frac{\partial r_{jk}}{\partial v_{jk}} = \frac{-2\beta_{jj}}{(\alpha_j + 2\beta_{jj} \cdot x_j + \sum_{\substack{i \\ i \neq j}} \beta_{ij} \cdot x_i)} \cdot \frac{\partial x_j}{\partial v_{jk}} +$$

$$- \frac{\beta_{kj}}{(\alpha_j + 2\beta_{jj} \cdot x_j + \sum_{\substack{i \\ i \neq j}} \beta_{ij} \cdot x_i)} \cdot \frac{\partial x_k}{\partial v_{jk}} +$$

$$+ \frac{\beta_{jk}}{(\alpha_k + 2\beta_{kk} \cdot x_k + \sum_{\substack{i \\ i \neq k}} \beta_{ik} \cdot x_i)} \cdot \frac{\partial x_j}{\partial v_{jk}} +$$

$$+ \frac{2 \cdot \beta_{kk}}{(\alpha_k + 2\beta_{kk} \cdot x_k + \sum_{\substack{i \\ i \neq k}} \beta_{ik} \cdot x_i)} \cdot \frac{\partial x_k}{\partial r_{jk}} + 1 \qquad (12)$$

After substituting (10) in (12) we get at $x_i = 0$:

$$\frac{1}{e_{jk}} = \frac{\partial r_{jk}}{\partial v_{jk}} = \frac{-2 \cdot \beta_{jj}}{\alpha_j} \cdot \frac{\alpha_k}{\alpha_j + \alpha_k} - \frac{\beta_{kj}}{\alpha_j} \cdot \frac{-\alpha_j}{\alpha_j + \alpha_k} +$$

$$+ \frac{\beta_{jk}}{\alpha_k} \cdot \frac{\alpha_k}{\alpha_j + \alpha_k} + \frac{2 \cdot \beta_{kk}}{\alpha_k} \cdot \frac{-\alpha_j}{\alpha_j + \alpha_k} + 1$$

$$\frac{1}{e_{jk}} = \frac{-1}{\alpha_j \cdot \alpha_k \ (\alpha_j + \alpha_k)} \ (2 \cdot \beta_{jj} \cdot \alpha_k^2 - 2 \cdot \beta_{jk} \cdot \alpha_j \cdot \alpha_k + 2\beta_{kk} \cdot \alpha_j^2) + 1$$

So:

$$\boxed{e_{jk} = \frac{\alpha_j + \alpha_k}{(\alpha_j + \alpha_k) - 2 \cdot \dfrac{\beta_{jj} \cdot \alpha_k^2 - \beta_{jk} \cdot \alpha_j \cdot \alpha_k + \beta_{kk} \cdot \alpha_j^2}{\alpha_j \cdot \alpha_k}}} \qquad (13)$$

B. Elasticity of substitution between j and k (e_{jk}) at arbitrary inputlevels.

In the first part we started with a model based on q and x_i, but now the given model is based on Q and X_i:

$$\ln Q = a_o + \sum_i a_i . \ln X_i + \sum_i b_{ii} . (\ln X_i)^2 +$$

$$+ \sum_{i<i'} b_{ii'} (\ln X_i) (\ln X_{i'}) \qquad (14)$$

Our goal is to determine e_{jk} in the point $X_i = \eta_i$,

$i = 1, \ldots, n$

We rewrite (14) as:

$$\ln Q = a_o + \sum_i a_i \ln X_i + \tfrac{1}{2} \sum_{i,i'} \tilde{b}_{ii'} (\ln X_i - \ln \eta_i).$$

$$(\ln X_{i'} - \ln \eta_{i'}) + \sum_{i,i'} \tilde{b}_{i,i'} \ln X_i \ln \eta_{i'} + \text{constant}' \quad . \qquad (15)$$

$$= \text{constant} + \sum_i (a_i + \sum_{i'} \tilde{b}_{ii'} \ln \eta_{i'}) (\ln X_i - \ln \eta_i) +$$

$$+ \tfrac{1}{2} \sum_{i,i'} \tilde{b}_{i,i'} (\ln X_i - \ln \eta_i) (\ln X_{i'} - \ln \eta_{i'}) \qquad (16)$$

With: $\tilde{b}_{ii} = 2\, b_{ii}$; $\tilde{b}_{ii'} = b_{ii'}$ $(i \neq i')$

We apply (13) to determine e_{jk} in the point $X_i = \eta_i (i=1,\ldots,p)$

We define x_i in (1) as:

$$x_i = \ln X_i - \ln \eta_i = \ln ({}^{X_i}/_{\eta_i}).$$

When we compare (16) with (12) then the coefficients in (13) became:

$$\beta_{jj} = \tfrac{1}{2} \tilde{b}_{jj} = b_{jj}; \; \beta_{jj'} = \tilde{b}_{jj'} = b_{jj'} \; (j \neq j')$$

$$\alpha_j = a_j + \sum_{j'} \tilde{b}_{jj'} . \ln \eta_j = a_j + 2\, b_{jj} . \ln \eta_j +$$

$$+ \sum_{j' \neq j} b_{jj'} \; . \; \ln \eta_{j'} \; .$$

APPENDIX III.1

Estimation some production models with respect to the input "drugs".

In Chapter IV is assumed that the disturbances in the regression model are independent of the inputs. If this assumption is not satisfied, then there is a simultaneous equations bias. In Chapter III we remark that especially with respect to the input "drugs" there may be a bias. In this appendix we test two alternative specifications with respect to the input "drugs".
In the first model it is assumed that the "drugs and dressings" and the "other (para-)medical means" are dependent of the output. We suppose that the drugs are directly variable with the output level.
In the second model the use of drugs is supposed to be endogeneous with respect to the other inputs and not to the output (see Feldstein, 1967b).

Model 1: (Drugs are endogeneous with respect to the output).

$$\text{WADM} = f1\ (\text{inputs}) \quad \text{"production function"} \tag{1}$$
$$\text{DD} = f2\ (\text{WADM}) \tag{2}$$
$$\text{PMM} = f3\ (\text{WADM}) \tag{3}$$

Model 2: (Drugs are endogeneous with respect to the inputs).

$$\text{DD} = f4\ (\text{inputs; function variables}) \tag{4}$$
$$\text{PMM} = f5\ (\text{inputs; function variables}) \tag{5}$$
$$\text{WADM} = f6\ (\text{inputs}, \widehat{\text{DD}}, \widehat{\text{PMM}}) \quad \text{"production function"} \tag{6}$$

We have estimated these two models, starting with a Cobb-Douglas specification of the production function.

<u>Estimation results model 1:</u>

$$\ln \text{WADM} = \underset{(0,34)}{3,52} + \underset{(0,08)}{0,22} \ln \text{RN} - \underset{(0,03)}{0,04} \ln \text{St.N} - \underset{(0,02)}{0,01} \ln \text{ON} +$$
$$+ \underset{(0,04)}{0,10} \ln \text{PM} + \underset{(0,06)}{0,05} \ln \text{Spec.} - \underset{(0,035)}{0,007} \ln \text{Fac} + \underset{(0,12)}{0,69} \ln \text{Bed}$$
$$\bar{R}^2 = 0,93 \quad \text{(1a)}$$

$$\ln \text{DD} = \underset{(0,04)}{1,11} \ln \text{WADM} - \underset{(1,90)}{4,91} \qquad \bar{R}^2 = 0,46 \quad \text{(2a)}$$

$$\ln \text{PMM} = \underset{(0,07)}{1,09} \ln \text{WADM} - \underset{(1,14)}{4,69} \qquad \bar{R}^2 = 0,69 \quad \text{(3a)}$$

These 3 equations are estimated independently of each other. Equation (2a) and (3a) are estimated with the observed outputs per hospital.
The double-logaritmic specification of (2a) and (3a) are in conformity with the Cobb-Douglas specification.

The results in equation (1a) are very similar to those in table 9. There is a difference with respect to the paramedical staff (PM). This is connected with the strong relation between drugs and the paramedical staff. In model (2) we come back to this.
The estimates in equation (2a) and (3a) imply that an increase of the weighted admissions with 1% leads to an increase of 1,11% (σ = 0,04) of DD and 1,09 % (σ = 0,07) of PMM.
These increases seems very high.

Estimation results model 2

Model 2 is estimated recursively (Johnston, 1963)

$$\begin{aligned}
\ln DD = {} & \underset{(2,80)}{14,41} + \underset{(0,29)}{0,54} \ln RN - \underset{(0,109)}{0,087} \ln St.N - \underset{(0,07)}{0,19} \ln ON + \\
& + \underset{(0,17)}{0,41} \ln PM + \underset{(0,422)}{0,099} \ln Beds - \underset{(0,23)}{0,18} \ln Spec. + \qquad (4\ a) \\
& + \underset{(0,12)}{0,28} \ln Fac. - \underset{(0,44)}{0,22} \ln Dsgr. - \underset{(0,10)}{0,22} \ln ENT + \\
& + \underset{(0,20)}{0,34} \ln Spec.tr. - \underset{(0,19)}{0,99} \ln Outp. \qquad R^2 = 0,76
\end{aligned}$$

$$\begin{aligned}
\ln PPM = {} & \underset{(1,44)}{8,63} + \underset{(0,15)}{0,51} \ln RN - \underset{(0,056)}{0,054} \ln St.N - \underset{(0,037)}{0,069} \ln ON + \\
& + \underset{(0,09)}{0,52} \ln PM + \underset{(0,216)}{0,011} \ln Beds + \underset{(0,12)}{0,12} \ln Spec. + \qquad (5\ a) \\
& + \underset{(0,063)}{0,47.10^{-3}} \ln Fac. + \underset{(0,224)}{0,050} \ln Dsgr. - \underset{(0,050)}{0,024} \ln ENT + \\
& + \underset{(0,10)}{0,27} \ln Spec.tr. - \underset{(0,095)}{0,054} \ln Outp. \qquad \bar{R}^2 = 0,90
\end{aligned}$$

$$\begin{aligned}
\ln WADM = {} & \underset{(1,72)}{4,08} - \underset{(0,13)}{0,20} \ln RN - \underset{(0,0306)}{0,0071} \ln St.N + \underset{(0,022)}{0,036} \ln ON + \\
& - \underset{(0,12)}{0,36} \ln PM + \underset{(0,12)}{0,65} \ln Beds - \underset{(0,067)}{0,066} \ln Spec. + \\
& + \underset{(0,035)}{0,017} \ln Fac. + \underset{(0,23)}{0,87} \ln \widehat{PMM} + \underset{(0,052)}{0,043} \ln \widehat{DD} \\
& \qquad \bar{R}^2 = 0,94
\end{aligned}$$

The elasticity of the paramedical staff with respect to "drugs and dressings" (DD) is 0,41 (σ = 0,17) and with respect to "other (para-)medical means" (PMM) is 0,52 (σ = 0,09).
For the "drugs and dressings" (DD) we have significant elasticities for the "registered nurses" (RN) (positive), the "other nursing staff (ON) (negative) and the "facility-index" (Fac.) (positive).

For the "other (para-)medical means (PMM) there are significant elasticities for "registered nurses" (RN) (positive), the "other nursing staff" (ON) (negative) and the "paramedical staff" (positive).
Some variables for the hospital function have significant parameters. For "drugs and dressings" (DD) are the specialist training (Spec.tr.) and the outpatient-variable very important.
Hospitals with a training programme for specialists have a higher use of "drugs and dressings" and of "other (para-) medical means". The very significant effect of the outpatient-variable on "other (para-)medical means" is related to the fact that "drugs and dressings" of outpatient-patient are not supplied by the hospital.

When we substitute (4 a) and (5 a) in (6 a), we can compare the productionfunction of model (2) with model (1). Then we get:

$$\ln \mathrm{WADM} = 0{,}22 \ln \mathrm{RN} - 0{,}050 \ln \mathrm{St.N} - 0{,}016 \ln \mathrm{ON} +$$

$$+ 0{,}075 \ln \mathrm{PM} + 0{,}66 \ln \mathrm{Beds} + 0{,}046 \ln \mathrm{Spec.} +$$

$$+ 0{,}045.10^{-4} \ln \mathrm{Fac.} + a$$

Comparing this with the results of the Cobb-Douglasmodel in Chapter IV.1 (table 9) there is a great similarity.
When we compare model (1) and (2), we see that the explanatory-power for "drugs and dressings" and for "the other (para)-medical means" are much higher in model (2) as in model (1). This implies that the use of drugs is highly dependent of the other inputs and the function variables.

General conclusion

The general conclusion is that for the production function estimates there is no significant difference if we suppose that "drugs" are or are not exogeneous to the output.
The second model (drugs depend on the other inputs and the hospital function) gives a better explanation for the "drugs" than model 1 (drugs are endogeneous with respect to the output).

APPENDIX IV.1

Comparison of some output measurements for the (weighted) admissions.

In table 42 we compare the estimation results of 5 models with 5 different output measurements. They all concern the problem of heterogenity in the number of admissions. In model (1) we start with the number of admissions without any differentiation. The coefficient of the "student nurses" is significant negative. That is the reason we reject this model.
In model (2) we add some variables with respect to the hospital function to correct for heterogenity in the number of admissions. The coefficient of the "student nurses" is still significant negative.
In model 3 we take into account more variables with respect to the hospital function (nursing-aid training and clerkship training). The coefficient of "student nurses" is still negative. Feldstein (1967b) remarks, like Klein, that the function variables are put in the production function in the same way as is done in the cost function. Therefore we set the function variables in model (4) on a proportional basis to the output. This gives little difference with respect to model (2). In model (5) the output is measured by the weighted admissions (see Chapter III). There are no significant negative variables. Comparing all the results we prefer the output measurement via the weighted admissions. An advantage is also that we have to estimate less parameters in this case.
In model 1 to 5 inputs like "household staff, clerical staff and other household costs" are not taken into account (see also Chapter III). In model 6 we test the consequences of this. The coefficients of these three variables are not highly significant, but there is some influence on other coefficients (for example: the number of beds).

Table 42: Estimation results Cobb-Douglas production function (log-log specification) with alternative output measurements for the admissions.

Inputs \ Output	Admissions (1)	Admissions (2)	Admissions (3)	Admission (proport. effect functionvar.) (4)	weighted admissions (5)		weighted admissions (6)
1. Constant	3,7252	2,516	2,4987	1) 3,2396	9,9995		10,443
	(0,5777)	(0,899)	(0,9004)	(0,6239)	(0,5684)		(0,593)
2. RN	0,2265	0,1775	0,2048	2) 0,1986	0,1646		0,1185
	(0,0903)	(0,1775)	(0,0811)	(0,0813)	(0,0888)		(0,0913)
3. StN	-0,0642	-0,0401	-0,0506	3) -0,0490	-0,0379		-0,0488
	(0,0315)	(0,0298)	(0,0289)	(0,0291)	(0,0310)		(0,0308)
4. ON	-0,0327	-0,0157)	-0,0194	4) -0,0234	0,0014		-0,0000
	(0,0208)	(0,0200)	(0,0198)	(0,0197)	(0,0205)		(0,0217)
5. PM	0,0013	0,0231	0,0450	5) 0,0517	0,0472		0,0192
	(0,0543)	(0,0549)	(0,0530)	(0,0528)	(0,0534)		(0,0568)
6. Beds	0,6860	0,681	0,6627	6) 0,6720	0,6752		0,457
	(0,1231)	(0,111)	(0,1107)	(0,1158)	(0,1211)		(0,148)
7. Fac.	0,0347	0,0083	0,0132	7) 0,0273	-0,0066		-0,0194
	(0,0358)	(0,0336	(0,0334)	(0,0334)	(0,0352)		(0,0354)
8. Spec.	-0,0229	0,224	0,0165	8) 0,0348	0,0378		0,0258
	(0,0637)	(0,0627)	(0,0619)	(0,0629)	(0,0627)		(0,0644)
9. DD	-0,0206	-0,0038	-0,0075	9) -0,0135	0,0097		0,0004
	(0,0231)	(0,0239)	(0,0237)	(0,0234)	(0,0227)		(0,0237)
10. PMM	0,0589	0,0663	0,0651	10) 0,0502	0,1027		0,0980
	(0,0594)	(0,0547)	(0,0547)	(0,0549)	(0,0585)		(0,0599)
11. Dsgr	-	0,139	0,1524	11) 0,0020		household staff	0,1268
	-	(0,114)	(0,1139)	(0,0015)			(0,0879)
12. ENT	-	0,1210	0,1315	12) 0,0101		household costs	0,0,986
	-	(0,0273)	(0,0261)	(0,00021)			(0,0783
13. Outp.	-	-0,0373	-0,0428	13) -0,0020		clerical staff	0,0948
	-	(0,0547)	(0,0547)	(0,0018			(0,0840)
14. Spec. tr.	-	-0,0079	0,0146	14) 0,0193			
	-	(0,0407)	(0,056)	(0,0392)			
15. Clerk. tr.	-		0,0550				
			(0,0366)				
16. NAID tr.	-		-0,0260				
			(0,0309)				
N	107	107	107	197	107		104
R^2	0,91	0,93	0,94	0,99	0,94		0,95

APPENDIX IV.2

Production functions with the number of specialists converted to full-time basis.

In the estimated production function in Chapter IV the input "specialists" is measured by the number of specialists working in a hospital. The conversion to full-time basis is not available for the year 1971. For the year 1972 we have from a smaller group of hospitals the conversion to full-time basis.
We first present some figures and then we estimate a production function with the converted number of specialists. We make a difference between attending specialists like surgeons, paediatricians, neurosurgeons, cardiologists, lungspecialists, and supporting specialists like clinical chemists, radiologists, anaesthesiologists and bacteriologists.

Tabel 43: Number of specialists, converted and unconverted, devided in two groups, 1971 (N = 78).

	average	coeff. of variation	ratio unconv. to conv. number
number of specialists	25,78	44,6	1,23
number of converted specialists	20,90	55,6	
number of attending specialists	20,03	44,5	1,20
number of converted specialists	16,71	53,2	
number of supporting specialists	5,76	55,9	1,34
number of converted supporting spec.	4,30	68,3	

In table 43 we see that on average a hospital has about 26 specialists, converted to full-time basis this is about 21. The part-time ratio is on average 1,23. With respect to the attending staff we see about the same figures. The number of attending staff-members is 20 and on full-time basis nearly 17.
The number of supporting specialists is nearly 6 and converted to full-time basis 4,3. The part-time ratio for the supporting staff is greater than for the attending staff. In column (2) we give the coefficients of variation. They are high, but this is related to the number of beds of the hospitals. Therefore we present the figures in relation to a division of the hospitals in 6 classes with respect to the number of beds (table 44).
In the smaller hospitals there are less specialists than in the bigger hospitals.
In table 45 we give the ratio of the unconverted to converted number of specialists.

Table 44: Number of specialists, converted and unconverted for 6 classes of the number of beds (size-class).

size-class	number attend. spec.	conv. number attend. spec.	number off supp. spec.	conv. number of supp. spec.	number of spec.	conv. number of spec.
B < 150	12,11	6,97	2,56	1,18	14,67	8,15
150 ≤ B < 200	12,00	8,65	2,75	2,28	14,75	10,71
200 ≤ B < 300	15,41	11,37	4,29	2,98	19,71	14,35
300 ≤ B < 400	20,08	17,75	5,75	4,76	25,83	22,49
400 ≤ B < 600	26,43	23,16	8,57	7,46	35,00	27,77
B ≥ 600	40,50	38,06	12,17	11,77	52,67	49,82
Totaal	20,03	16,71	5,76	4,30	25,78	20,90

Table 45: Ratio of converted to unconverted number of specialists per size-class.

size-class	ratio all spec.	ratio attend. spec.	ratio supp. spec.
B < 150	1,80	1,74	2,16
150 < B < 200	1,38	1,39	1,21
200 < B < 300	1,37	1,36	1,44
300 < B < 400	1,15	1,13	1,21
400 < B < 600	1,26	1,14	1,15
B ≥ 600	1,06	1,06	1,03
Totaal	1,20	1,20	1,34

In the smaller hospitals the specialists are more part-time than in the bigger hospitals (see also Van Montfort c.s., 1979).

Production function with the converted number of specialists

In table 46 we compare the estimation results of some Cobb-Douglas production functions, one with the unconverted and one with the converted number of specialists.
Because the lower number of hospitals the results are maybe not representative. But in comparing the different models we get some indication.

The converted number of specialists have significant coefficients. The coefficients of the other inputs in the model with the converted number of specialists are comparable to those in the model with the unconverted number of specialists. The impact of the attending staff is higher than the impact of the supporting staff.

Table 46: Cobb-Douglas production functions with converted resp. unconverted number of specialists.

	$\hat{\beta}$	$\hat{\sigma}$	$\hat{\beta}$	$\hat{\sigma}$	$\hat{\beta}$	$\hat{\sigma}$	$\hat{\beta}$	$\hat{\sigma}$
Constant	9,426	(0,789)	9,649	(0,739)	9,652	(0,825)	10,036	(0,817)
Beds	0,809	(0,173)	0,784	(0,162)	0,808	(0,174)	0,748	(0,167)
RN	0,088	(0,142)	0,049	(0,133)	0,085	(0,143)	0,057	(0,134)
PMM	0,266	(0,096)	0,171	(0,089)	0,156	(0,098)	0,161	(0,092)
ON	0,00016	(0,0340)	-0,00015	(0,0314)	0,007	(0,036)	0,007	(0,033)
PM	0,010	(0,070)	-0,047	(0,069)	0,015	(0,071)	-0,041	(0,069)
DD	-0,042	(0,040)	-0,051	(0,038)	-0,041	(0,041)	-0,045	(0,038)
Fac.	-0,014	(0,057)	-0,029	(0,053)	-0,011	(0,057)	-0,019	(0,055)
St.N	-0,049	(0,039)	-0,058	(0,035)	-0,046	(0,039)	-0,055	(0,035)
Spec.	0,113	(0,104)						
Conv.spec.			0,266	(0,092)				
Attend.spec.					0,034	(0,109)		
Supp.spec.					0,062	(0,056)		
Conv.attend.spec.							0,153	(0,107)
Conv.supp.spec.							0,094	(0,058)
R^2	0,95		0,96		0,95		0,96	
N	57		57		57		57	
$\bar{R}^2$	0,94		0,95		0,94		0,95	

Table 47: Correlation matrix of the estimates - part 1

	C	Staff	Beds	Spec.	Fac.	Drugs	$(\text{Staff})^2$	$(\text{Beds})^2$	$(\text{Spec.})^2$	$(\text{Fac.})^2$
C	1.000000									
Staff	.484486	1.000000								
Beds	-.625122	-.774797	1.000000							
Spec.	.128108	-.301399	-.079463	1.000000						
Fac.	.633040	-.082908	-.293096	.128475	1.000000					
Drugs	-.803405	-.485747	.267815	-.055580	-.298247	1.000000				
$(\text{Staff})^2$	.083276	.450431	-.322605	-.293639	-.165233	-.052359	1.000000			
$(\text{Beds})^2$	.110636	.226489	-.406704	.011253	.066103	.136507	.611825	1.000000		
$(\text{Spec.})^2$	.000511	-.015666	-.124655	.207064	-.016059	.099506	.108564	.129390	1.000000	
$(\text{Fac.})^2$	.288506	-.126083	-.182622	.099545	.594267	-.007180	.058480	.047197	.048313	1.000000
$(\text{Drugs})^2$	.436570	.328250	.048303	.025833	.001196	-.834087	.058395	-.143848	-.075378	-.163135
Staff Beds	-.107288	-.383437	.398107	.200573	.062286	-.047713	-.871601	-.877075	-.044118	-.045443
Staff Spec.	.023493	-.203784	.089365	.366205	.016544	-.037599	-.340941	.035653	-.357976	.031901
Staff Fac.	.203671	.292704	-.305062	-.096003	.174645	-.126836	-.462801	-.138791	.055847	-.273058
Staff Drugs	-.317516	-.711465	.379114	.209193	.185767	.520095	-.271970	.319110	.041504	.084829
Beds Spec.	-.031034	.226760	-.025744	-.550519	-.048456	.012813	.311153	-.147851	-.151382	.085228
Beds Fac.	-.324631	-.178553	.488675	-.096468	-.490400	-.006334	.345333	.060329	-.052664	-.368335
Beds Drugs	.479113	.655095	-.607432	-.026583	.078203	-.419339	.189628	-.307828	-.029576	.135208
Spec. Fac.	.156015	-.179492	-.047492	.507967	.339591	-.112397	-.138246	.028605	-.090870	.048284
Spec. Drugs	-.101211	.169805	.067119	-.556647	-.089195	.127055	.127858	.094930	-.040275	-.288012
Fac. Drugs	-.379055	.093403	-.055015	-.100875	-.539366	.414659	.190253	-.012175	.056420	.128992

Correlation matrix of the estimates - part 2

	$(\text{Drugs})^2$	Staff x Beds	Staff x Spec.	Staff x Fac.	Staff x Drugs	Beds x Spec.	Beds x Fac.	Beds x Drugs	Spec. x Fac.	Spec. x Drugs
$(\text{Drugs})^2$	1.000000									
Staff Beds	.108911	1.000000								
Staff Spec.	.046647	.124124	1.000000							
Staff Fac.	-.012546	.291004	-.161195	1.000000						
Staff Drugs	-.510734	-.083145	.110987	.004474	1.000000					
Beds Spec.	-.084194	-.186193	-.683098	.108895	-.092710	1.000000				
Beds Fac.	.217749	-.241480	.122425	-.634719	-.004036	-.093233	1.000000			
Beds Drugs	.101047	.031424	-.049311	.083754	-.780901	.194570	-.207353	1.000000		
Spec. Fac.	.089853	.101649	-.031476	-.121392	.132136	-.285961	-.141081	-.105562	1.000000	
Spec. Drugs	.100108	-.0 4843	-.274914	.096739	-.197782	-.134888	.115484	-.187973	-.000170	1.000000
Fac. Drugs	-.287143	-.076267	-.003590	-.221025	-.209052	.157433	-.172334	.150577	-.377702	-.139075 .

Correlation matrix of the estimates - part 3

	Fac. drugs
Fac. Drugs	1.000000

Table 48: Correlation matrix of the variables - part 1

	Staff	Beds	Spec.	Fac.	Drugs	$(\text{Staff})^2$	$(\text{Beds})^2$	$(\text{Spec.})^2$	$(\text{Fac.})^2$
Staff	1.000000								
Beds	.969171	1.000000							
Spec.	.863105	.848457	1.000000						
Fac.	.838238	.822876	.735051	1.000000					
Drugs	.889372	.868263	.775167	.759971	1.000000				
$(\text{Staff})^2$	.997830	.968031	.862652	.824226	.890582	1.000000			
$(\text{Beds})^2$	.968055	.998587	.847492	.814520	.868984	.970066	1.000000		
$(\text{Spec.})^2$	.853069	.837631	.996615	.715578	.766898	.856182	.839463	1.000000	
$(\text{Fac.})^2$	.884905	.877956	.784837	.957774	.812161	.883295	.878140	.775904	1.000000
$(\text{Drugs})^2$	.889223	.867375	.773962	.753896	.999223	.892329	.869513	.767460	.811610
Staff Beds	.992025	.989085	.862226	.826719	.887232	.993982	.990810	.854915	.887746
Staff Spec.	.952379	.930061	.972029	.793051	.852972	.955272	.932152	.970517	.855470
Staff Fac.	.917373	.901126	.803621	.980485	.830313	.911648	.898340	.790816	.984081
Staff Drugs	.984724	.956786	.852643	.821943	.952519	.986549	.958385	.845437	.880111
Beds Spec.	.936222	.939123	.975772	.786889	.841198	.938987	.940908	.973621	.850768
Beds Spec.	.902635	.988205	.792133	.985853	.817128	.895242	.894495	.777772	.982071
Beds Fac.	.967356	.977472	.845284	.815937	.951294	.969643	.978915	.847403	.878887
Beds Drugs	.905677	.891551	.872154	.964795	.820118	.900928	.889314	.863873	.973844
Spec. Fac.	.914130	.896664	.978803	.771260	.884374	.916799	.898195	.977057	.832674
Spec. Drugs	.880917	.865030	.772273	.991882	.828060	.871872	.960089	.756773	.975880
Fac. Drugs	.955845	.962867	.837764	.794458	.868575	.955779	.961995	.828630	.851741

Correlation matrix of the variables - part 2

	$(\text{Drugs})^2$	Staff x Beds	Staff x Spec.	Staff x Fac.	Staff x Drugs	Beds x Spec.	Beds x Fac.	Beds x Drugs	Spec. x Fac.	Spec. x Drugs
(Drugs)	1.000000									
Staff Beds	.888390	1.000000								
Staff Spec.	.854094	.951912	1.000000							
Staff Fac.	.828132	.912818	.876903	1.000000						
Staff Drugs	.853812	.981144	.942721	.905621	1.000000					
Beds Spec.	.841706	.946796	.994374	.868561	.927408	1.000000				
Beds Fac.	.814035	.902068	.861851	.997943	.889916	.858867	1.000000			
Beds Drugs	.951915	.980930	.930486	.898419	.987948	.930860	.890233	1.000000		
Spec. Fac.	.818066	.902737	.913621	.986523	.894674	.910017	.984275	.888744	1.000000	
Spec. Drugs	.884857	.915082	.985803	.849283	.928374	.984419	.835613	.922360	.897666	1.000000
Fac. Drugs	.824503	.873559	.838788	.993410	.875801	.831448	.994747	.873314	.979031	.823435
Dep. var.	.868524	.965689	.919304	.875957	.948786	.918642	.867237	.955057	.867482	.889352

APPENDIX IV.4

Some statistical aspects of the translog model of the weighted admissions with 5 inputs.

In this appendix the hypothesis of homoscedasticity of the translog model for weighted admissions with 5 inputs is tested (Feldstein, 1967, pages 52-54).
First the hospitals are ordered (from low to high) on the basis of the fitted values from the regressionmodel.
Then 4 groups are formed with as much as possible the same number of hospitals (i = 1, 2, 3, 4). Then the standard deviation of the residuals are calculated of the hospitals which belong to a specific group ($\hat{\sigma}_i$).
These standard deviations are compared with the standard deviation of all residuals ($\hat{\sigma}$) by calculating a likelihood-ratio λ.

If t_i is the number of hospitals per group i and $t = \sum_{i=1}^{4} t_i$,

then $\lambda = \dfrac{\prod_{i=1}^{4} (\hat{\sigma}_i)^{t_i}}{(\hat{\sigma})^t}$; $-2 \ln \lambda$ has approximately a χ^2-distribution with 3 degrees of freedom.

If $-2 \ln \lambda$ is greater then χ^2_3; 0,05 (= 7,81), then the null-hypothesis of homoscedasticity is rejected at the 95%-level.
In our case $-2 \ln \lambda = 2{,}3211$, so the null-hypothesis is accepted.
Also the plot of the residuals and the fitted values (figure 4) shows no irregularities. (Draper and Smith, 1966).
In the figures 5-11 the residuals are plotted against the number of beds, the year of construction, the training programme (specialist training), the ownership, the length of stay, the expected length of stay and the difference between the real and the expected length of stay.

Figures 5-8 give no indications to adjust the model.
From the other figures we get information with respect to the interpretation of the residuals (see Chapter I en V).

Figure 8: Plot of the residuals and the ownership

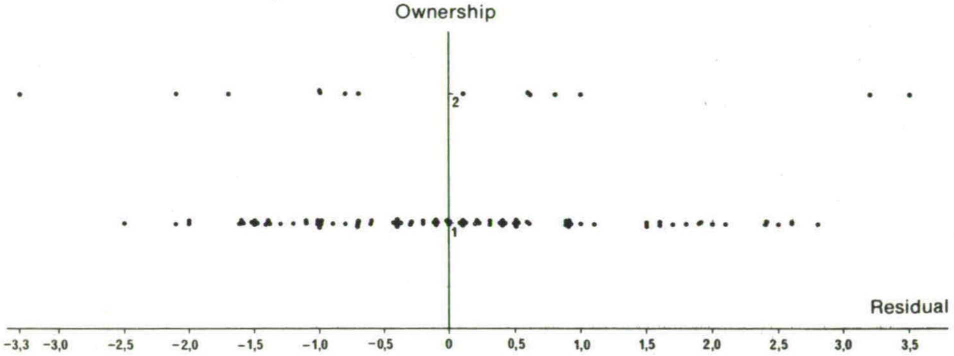


Figure 9: Plot of the residuals and the length of stay

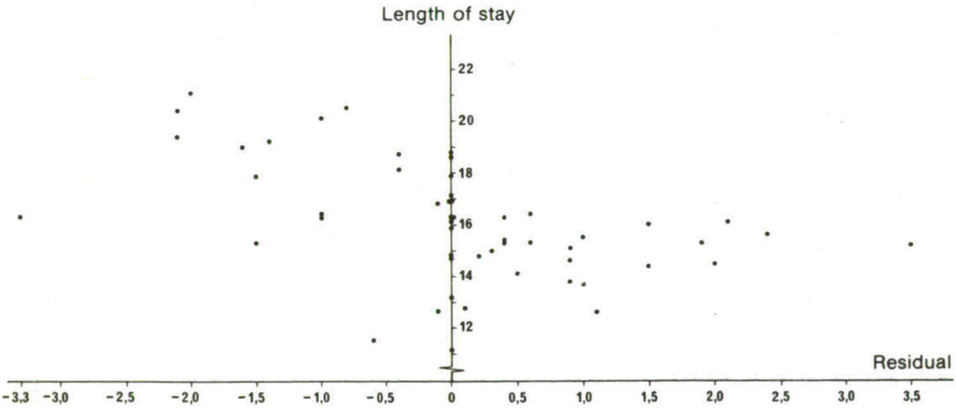


Figure 6: Plot of the residuals and the year of construction

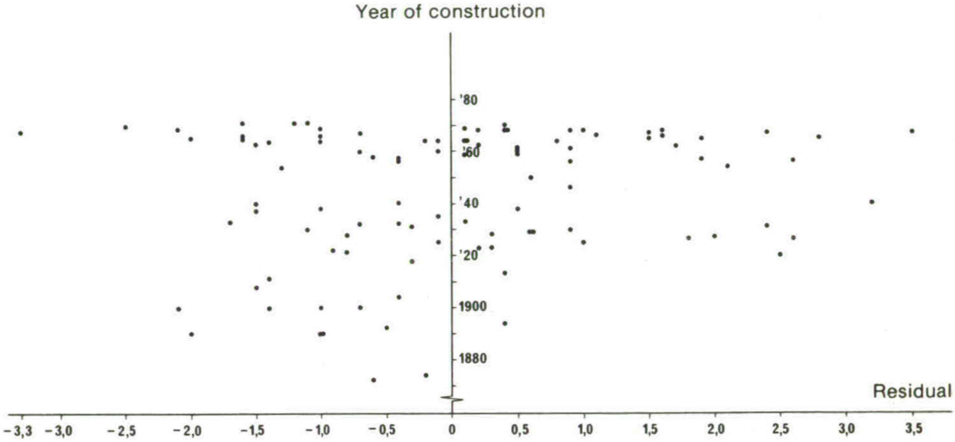


Figure 7: Plot of the residuals and the specialist training

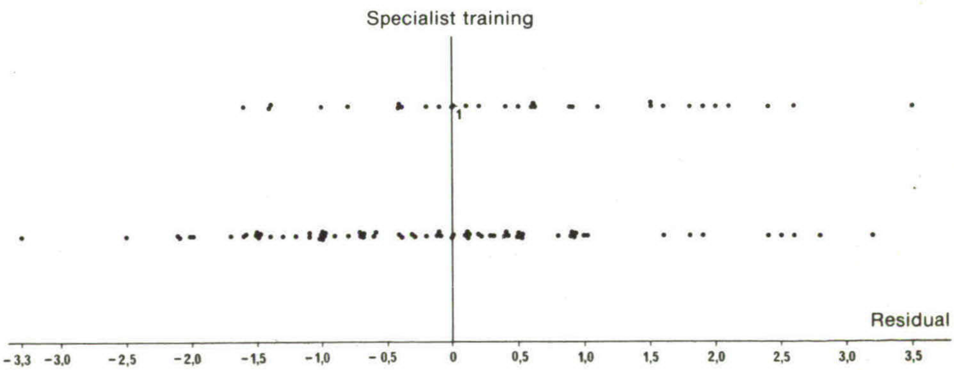


Figure 4: Plot of the fitted values and the residual (translog model weighted admissions and 5 inputs)

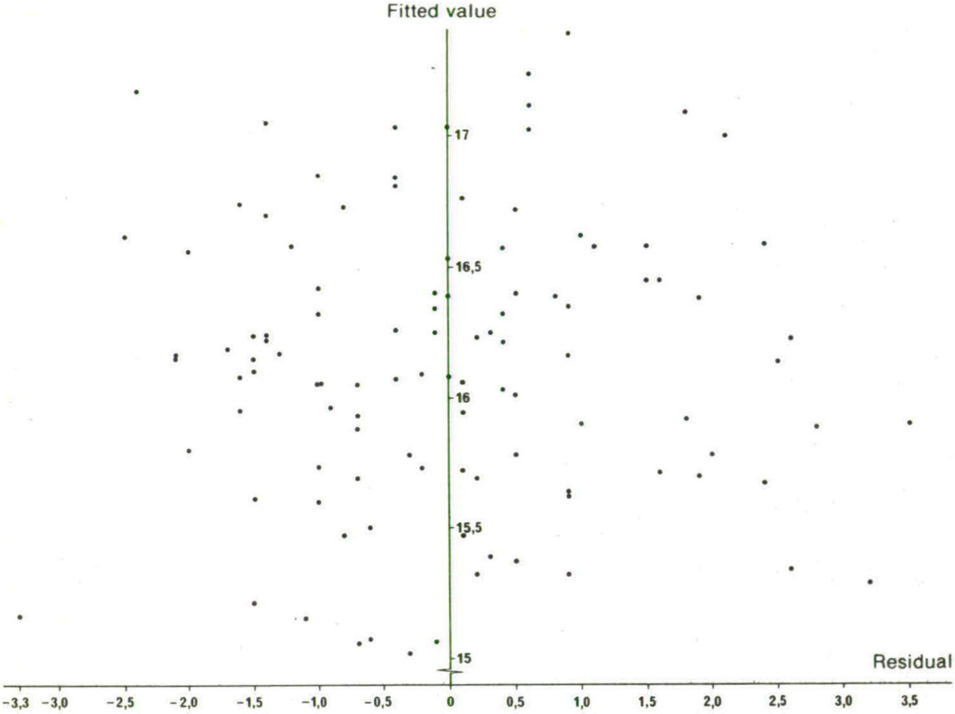


Figure 5: Plot of the residuals and the number of beds

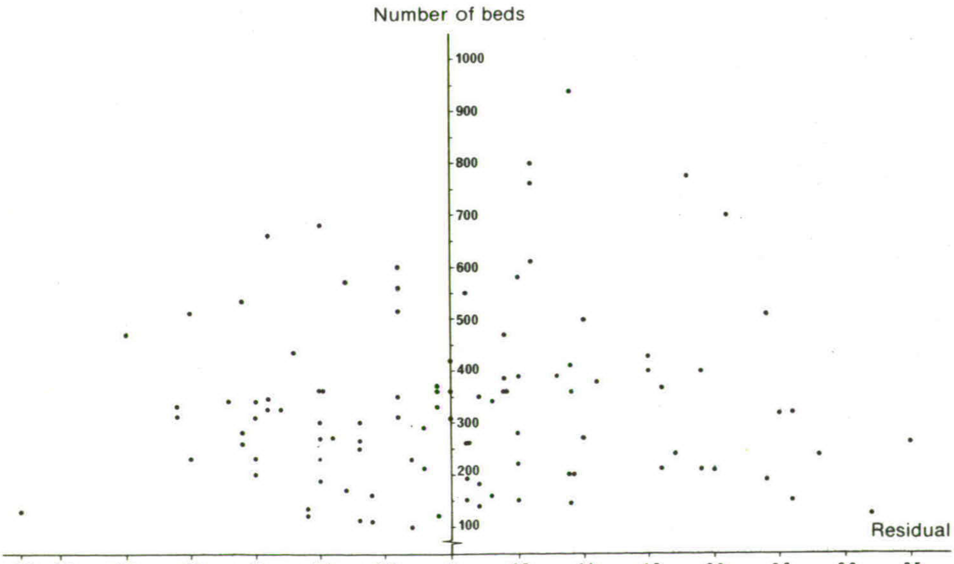


Figure 10: Plot of the residuals and the expected length of stay

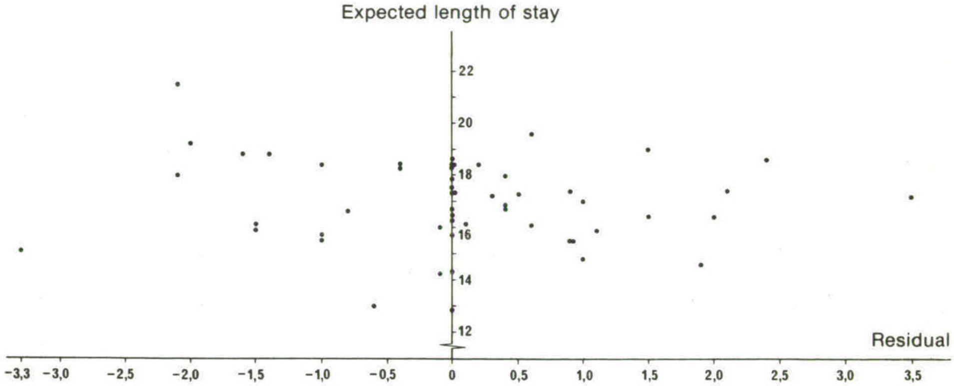
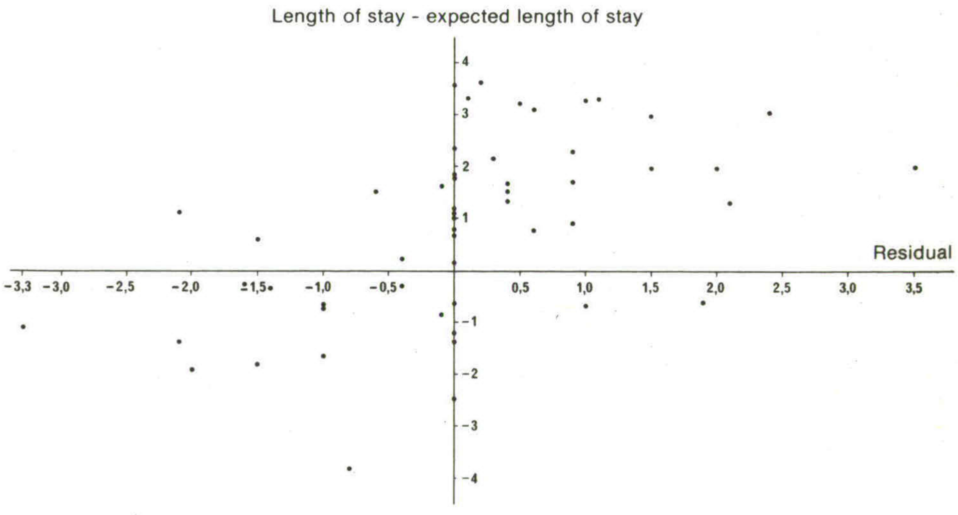


Figure 11: Plot of the residuals and the difference between the length of stay and the expected lenght of stay



APPENDIX IV.5

Output elasticities of the inputs at different input levels with respect to the weighted admissions (5 inputs model).

In table 49, 50 and 51 of this appendix we calculate the output elasticities of some inputs at different input levels based on the translog model of the weighted admissions with 5 inputs.

Table 49: Output elasticities of some inputs at varying levels of the number of beds, based on the translog production function of the weighted admissions with 5 inputs.

function group	inputlevel: number of beds	output elasticities ($\hat{\mu}$) and standard deviation ($\hat{\sigma}$) of: staff $\hat{\mu}$	staff $\hat{\sigma}$	beds $\hat{\mu}$	beds $\hat{\sigma}$	specialists $\hat{\mu}$	specialists $\hat{\sigma}$
I	125	0,05	0,63	1,45	0,73	-0,55	0,32
	150	0,11	0,38	1,15	0,42	-0,32	0,21
	175	0,16	0,21	0,89	0,21	-0,13	0,14
	200	0,21	0,20	0,67	0,24	0,03	0,13
	225	0,25	0,32	0,47	0,40	0,17	0,17
II	250	0,26	0,20	0,73	0,19	-0,11	0,13
	275	0,29	0,16	0,57	0,16	0,00	0,11
	300	0,32	0,22	0,42	0,26	0,11	0,13
	325	0,35	0,32	0,29	0,39	0,21	0,16
III	350	0,33	0,18	0,78	0,19	-0,05	0,09
	400	0,38	0,17	0,55	0,19	0,11	0,08
	450	0,42	0,29	0,36	0,37	0,26	0,14
	500	0,46	0,43	0,18	0,55	0,39	0,21
	550	0,49	0,57	0,02	0,72	0,50	0,27
IV	600	0,50	0,27	0,56	0,26	0,09	0,12
	650	0,53	0,28	0,43	0,29	0,19	0,14
	700	0,56	0,34	0,31	0,38	0,28	0,17
	750	0,38	0,41	0,19	0,47	0,36	0,20
	800	0,60	0,49	0,08	0,58	0,44	0,24

Table 50: Output elasticities of some inputs at varying levels of the staff, based on the translog production function of the weighted admissions with 5 inputs.

function-group	input level: staff	output elasticities ($\hat{\mu}$) and standard deviations ($\hat{\sigma}$) of: staff $\hat{\mu}$	staff $\hat{\sigma}$	beds $\hat{\mu}$	beds $\hat{\sigma}$	specialists $\hat{\mu}$	specialists $\hat{\sigma}$
	75	0,39	0,90	0,61	0,89	-0,15	0,38
	100	0,29	0,49	0,71	0,49	-0,12	0,23
	125	0,21	0,22	0,78	0,22	-0,09	0,14
I	150	0,15	0,23	0,85	0,23	-0,07	0,14
	175	0,10	0,42	0,90	0,41	-0,05	0,19
	200	0,31	0,19	0,61	0,18	-0,06	0,12
II	225	0,26	0,18	0,65	0,17	-0,04	0,12
	250	0,23	0,29	0,69	0,28	-0,03	0,15
	275	0,20	0,41	0,72	0,40	-0,02	0,20
	300	0,40	0,22	0,57	0,25	0,07	0,09
III	350	0,35	0,16	0,62	0,16	0,09	0,08
	375	0,32	0,23	0,65	0,20	0,10	0,11
	400	0,64	0,62	0,39	0,65	0,08	0,25
	450	0,60	0,47	0,43	0,49	0,09	0,20
	500	0,56	0,35	0,47	0,37	0,10	0,15
IV	550	0,53	0,28	0,50	0,29	0,12	0,13
	600	0,56	0,27	0,53	0,27	0,13	0,13
	650	0,47	0,37	0,56	0,28	0,14	0,14
	700	0,45	0,38	0,58	0,34	0,14	0,17

Table 51: Output elasticities of some inputs at varying levels of the number of specialists, based on the translog model of the weighted admissions with 5 inputs.

function-group	input level spec.	output elasticities ($\hat{\mu}$) and standard deviations ($\hat{\sigma}$) of: staff $\hat{\mu}$	staff $\hat{\sigma}$	beds $\hat{\mu}$	beds $\hat{\sigma}$	specialists $\hat{\mu}$	specialists $\hat{\sigma}$
∧	12	0,14	0,31	0,43	0,32	0,08	0,22
	14	0,16	0,24	0,62	0,24	0,04	0,16
I	16	0,18	0,19	0,79	0,19	-0,07	0,07
∨	18	0,19	0,17	0,93	0,18	-0,13	0,12
∧	20	0,27	0,19	0,56	0,18	-0,01	0,13
II	22	0,28	0,16	0,68	0,15	-0,06	0,11
∨	24	0,29	0,15	0,78	0,15	-0,11	0,09
∧	26	0,34	0,18	0,36	0,21	0,18	0,13
	28	0,35	0,16	0,45	0,18	0,14	0,11
	30	0,36	0,15	0,53	0,17	0,11	0,09
III	32	0,37	0,15	0,61	0,16	0,07	0,07
	34	0,38	0,16	0,69	0,17	0,04	0,07
∨	36	0,38	0,18	0,76	0,19	0,01	0,08
∧	40	0,48	0,25	0,25	0,25	0,24	0,16
	45	0,50	0,25	0,39	0,24	0,18	0,13
	50	0,51	0,27	0,52	0,26	0,12	0,13
IV	55	0,52	0,29	0,64	0,29	0,07	0,14
	60	0,53	0,32	0,75	0,32	0,03	0,16
∨	65	0,54	0,35	0,84	0,36	-0,02	0,18

APPENDIX IV.6

Output elasticities of the inputs at different input levels with respect to the weighted admissions (7 inputs model).

In this appendix we calculate output elasticities of some inputs at different input levels based on the translog model of the weighted admissions with 7 inputs.

Table 52: Output elasticities of some inputs at varying levels of the number of beds, based on the translog production function of the weighted admissions with 7 inputs.

function-group	input: beds	registered nurses $\hat{\mu}$	registered nurses $\hat{\sigma}$	student nurses $\hat{\mu}$	student nurses $\hat{\sigma}$	paramed. staff $\hat{\mu}$	paramed. staff $\hat{\sigma}$
		output elasticities ($\hat{\mu}$) and standard deviations ($\hat{\sigma}$) of:					
I	120	0,08	0,60	-0,10	0,40	0,29	0,26
I	150	0,29	0,35	-0,07	0,25	0,18	0,16
I	180	0,48	0,18	-0,05	0,14	0,09	0,10
I	210	0,61	0,20	-0,03	0,13	0,03	0,10
I	240	0,73	0,32	-0,02	0,19	-0,03	0,15
II	230	0,10	0,25	0,10	0,19	0,24	0,14
II	260	0,23	0,13	0,12	0,12	0,18	0,09
II	290	0,32	0,14	0,13	0,11	0,13	0,08
II	320	0,41	0,22	0,15	0,14	0,09	0,10
III	350	0,09	0,16	0,26	0,12	0,17	0,11
III	390	0,19	0,12	0,27	0,10	0,12	0,08
III	400	0,21	0,13	0,28	0,10	0,11	0,08
III	450	0,32	0,23	0,29	0,26	0,05	0,10
III	500	0,42	0,35	0,30	0,22	0,01	0,14
IV	550	0,08	0,26	0,41	0,18	0,12	0,17
IV	600	0,16	0,24	0,43	0,16	0,08	0,15
IV	650	0,24	0,26	0,44	0,16	0,04	0,15
IV	700	0,30	0,30	0,44	0,18	0,00	0,16
IV	750	0,37	0,36	0,45	0,21	-0,03	0,17
IV	800	0,43	0,43	0,46	0,25	-0,06	0,19
IV	850	0,49	0,49	0,47	0,29	-0,08	0,21

APPENDIX IV.7

Investigation into the distribution of the estimators of the elasticities of substitution, based on a translog-production-function.

In appendix II.1 we have derived the formula for the calculation of the elasticities of substitution between the inputs, based on a translog production function.
The elasticity of substitution between input j and k, in the point $X_i = \eta_i$, is:

$$e_{jk} = \frac{(\alpha_j + \alpha_k)}{(\alpha_j + \alpha_k) - 2. \dfrac{b_{jj}.\alpha_k^2 - b_{jk}.\alpha_j.\alpha_k + b_{kk}.\alpha_j^2}{\alpha_j \cdot \alpha_k}} \qquad (1)$$

Here, α_j and α_k are the outputelasticities of respectively X_j and X_k, in the point $X_i = \eta_i$ $(i = 1,\ldots,p)$; b_{jj}, b_{kk} and b_{jk} are the coefficients of respectively the quadratic and the cross-terms of the inputs j and k.
We also have:

$$\alpha_j = a_j + 2\, b_{jj} \ln \eta_j + \sum_{\substack{i \\ i \neq j}} b_{ji} \ln \eta_i \qquad (2)$$

and similarly for α_k, where a_j is the coefficient of $\ln X_j$ in the translog model (IV.3).
One can estimate the elasticity of substitution between inputs j and k by substituting the least square estimators of the coefficients a_j, a_k, b_{ij} and b_{ik} (for all i) from the regression-analysis in formula (1) via (2).

We treat two methods for getting more insight in the distribution of the estimated elasticity of substitution.

A. Analytical method[1)]

We approximate $\hat{e}_{jk}$ by a Taylor expansion of formula 1, eliminating terms of the order of two or higher, as follows:

$$\hat{e}_{jk} \simeq e_{jk} + \frac{\partial e_{jk}}{\partial \alpha_j}(\hat{\alpha}_j - \alpha_j) + \frac{\partial e_{jk}}{\partial \alpha_k}(\hat{\alpha}_k - \alpha_k) + \frac{\partial e_{jk}}{\partial b_{jj}} \cdot (\hat{b}_{jj} +$$

$$- b_{jj}) + \frac{\partial e_{jk}}{\partial b_{kk}}(\hat{b}_{kk} - b_{kk}) + \frac{\partial e_{jk}}{\partial b_{jk}}(\hat{b}_{jk} - b_{jk}). \qquad (3)$$

1) Layard c.s. (1971), Humphries and Moroney (1975), Kmenta (1971).

The partial derivatives of e_{jk} are:

$$\text{a) } \frac{\partial e_{jk}}{\partial \alpha_j} = e_{jk}{}^2 \cdot \frac{b_{jj}\cdot\alpha_k(2\,\alpha_j + \alpha_k) - 2b_{jk}\,\alpha_j^2 - b_{kk}\,\alpha_j^2}{\alpha_k^2\,(\alpha_j + \alpha_k)^2} = \gamma_j$$

$$\text{b) } \frac{\partial e_{jk}}{\partial \alpha_k} = e_{jk}^2 \cdot \frac{b_{kk}\cdot\alpha_j(2\,\alpha_k + \alpha_j) - 2b_{jk}\alpha_k^2 - b_{jj}\,\alpha_k^2}{\alpha_j^2\,(\alpha_k + \alpha_j)^2} = \gamma_k$$

$$\text{c) } \frac{\partial e_{jk}}{\partial b_{jj}} = - \frac{\alpha_k \cdot e_{jk}^2}{\alpha_j\,(\alpha_j + \alpha_k)} = \gamma_{jj} \qquad (4)$$

$$\text{d) } \frac{\partial e_{jk}}{\partial b_{kk}} = - \frac{\alpha_j \cdot e_{jk}^2}{\alpha_k\,(\alpha_j + \alpha_k)} = \gamma_{kk}$$

$$\text{e) } \frac{\partial e_{jk}}{\partial b_{jk}} = \frac{2.e_{jk}^2}{(\alpha_j + \alpha_k)} = \gamma_{jk}$$

For an approximation of the standarddeviation of $\hat{e}_{jk}$ we need an estimate of the covariancematrix of $\lceil \hat{\alpha}_j;\hat{\alpha}_k;\hat{b}_{jj};\hat{b}_{kk};\hat{b}_{jk}\rceil$.
This matrix results from the regressionmodel.
Kmenta (1971) shows that $\hat{e}_{jk}$, assuming the translogmodel in IV.3.1 and the assmuptions that are made there, is asymptotically normally distributed, as N tends to ∞, with expectation e_{jk} and a variance which may be consistently estimated by.

$$\hat{\sigma}_{\hat{e}_{jk}} = |\hat{\gamma}_j;\hat{\gamma}_k;\hat{\gamma}_{jj};\hat{\gamma}_{kk};\hat{\gamma}_{jk}| \quad \begin{bmatrix} \text{estimated} \\ \text{covariance} \\ \text{matrix of} \\ \hat{\alpha}_j;\hat{\alpha}_k;\hat{\alpha}_{jj} \\ \hat{\alpha}_{kk} \text{ and } \hat{\alpha}_{jk} \end{bmatrix} \quad \begin{bmatrix} \hat{\gamma}_j \\ \hat{\gamma}_k \\ \hat{\gamma}_{jj} \\ \hat{\gamma}_{kk} \\ \hat{\gamma}_{jk} \end{bmatrix}$$

In table 53 we give the results of the analytic method for the translog model of the weighted admissions and 5 inputs, at the average inputlevels.
Comparing column (1) and (2), we conclude that in general the estimated standard deviations are rather high. It is not possible to draw very exact conclusions about the height of elasticities of substitution.
Assuming the estimators are approximately normally distributed, we can test the hypothesis that the elasticities of substitution are not smaller than 1 ($H_0: e_{jk} \geq 1$). For the elasticity of substitution between staff and beds the observed t-value $\left[\dfrac{1 - \hat{e}_{jk}}{\hat{\sigma}_{\hat{e}_{jk}}}\right]$ is 1,57 with a right tail probability of 0,06; for the elasticity of substitution of staff and specialists and of specialists and the facility index the right tail probability is 0,001.

Table 53. Estimated standard deviation of $\hat{e}_{jk}$ via the analytical method (translog model) of weighted admission and 5 inputs.

elasticity of substitution	$\hat{e}_{jk}$ [via (1)]	$\hat{\sigma}_{\hat{e}_{jk}}$ [via (5)]
staff and beds	0,31*	0,44
staff and spec.	0,04*	0,14
staff and fac.	-0,15	0,92
staff and drugs	0,92	1,86
beds and spec.	0,04*	0,12
beds and fac.	-0,17	0,97
beds and drugs	-2,71	13,47
spec. and fac.	-0,07*	0,38
spec. and drugs	0,17	0,83
fac. and drugs	-0,36	1,39

* Significantly smaller than 1 at 10% level.

This means that for these elasticities of substitution we can reject the null hypothesis. These results are conform the results in table 16, except for the elasticity of staff and specialists.

B. Simulation-procedure

We assume that the estimators ($\hat{a}_i$, $\hat{b}_{ij}$, for all i and j; and also $\hat{\alpha}_j$ for all j) of the parameters in the translogmodel have a multivariate normal distribution, with mean-vector the actually obtained parameter estimates and with covariance matrix the estimate of the covariance matrix from the same regression model.
So we assume that the translog model of IV.3.1. is the correct one, filling in the unknown parameters without estimates of them. For getting realisations of $\hat{e}_{jk}$ we use the simulation-method of Naylor et al. (1966). By simulating a large number (10.000) of realisations of $\hat{a}_j$, $\hat{a}_k$, $\hat{b}_{kk}$ and $\hat{b}_{jk}$ we can calculate 10.000 $\hat{e}_{jk}$'s via (1) and (2).
Then it is possible to calculate quite exactly the mean, standard deviation and the cumulative distribution of the estimator $\hat{e}_{jk}$.
We stipulate again that we assume the above mentioned model-specification.
The results of the simulation method is given in table 54.
We start from the translogmodel of the weighted admissions with 5 inputs and the average levels.
Column (1) gives the average of the 10.000 $\hat{e}_{jk}$'s, ($\bar{\hat{e}}_{jk}$) column (2) $s(\bar{\hat{e}})$ and in column (3) $s(\hat{e})$ ($s(\bar{\hat{e}}) = s(\hat{e})/\sqrt{10.000}$) (see Kleine). $s(\bar{\hat{e}})$ gives an indication of the accuracy of $\bar{\hat{e}}_{jk}$. But we are more interested in $s(\hat{e})$ and the distribution of $\hat{e}_{jk}$ and especially in the position of the "true" e_{jk} in this distribution (column (8)).
The standard deviations in column (3) are very high.

Table 54. Results simulation method for the translogmodel of weighted admission adn 5 inputs.

elasticity substitution	$\bar{\hat{e}}_{jk}$ (1)	$s(\bar{\hat{e}}_{jk})$ (2)	$s(\hat{e}_{jk})$ (3)	$P\{\hat{e}_{jk} < e_{jk}\}$ (4)	(5)	$P\{\hat{e}_{jk} < 0\}$ (6)	$P\{\hat{e}_{jk} < 1\}$ (7)	assumed e_{jk} via (1) (8)
staff/beds	-0,04	0,10	10,47	0,53	$P\{0 < \hat{e}_{jk} < 0{,}5\} = 0{,}57$	0,36	0,99	0,31
staff/spec.	-1,15	1,09	108,70	0,25	$P\{0 < \hat{e}_{jk} < 0{,}5\} = 0{,}55$	0,24	0,90	0,04
staff/fac.	-0,05	0,22	22,36	0,26	$P\{0 < \hat{e}_{jk} < 0{,}5\} = 0{,}34$	0,50	0,92	-0,15
staff/drugs	0,02	0,15	15,06	0,91	$P\{0 < \hat{e}_{jk} < 0{,}5\} = 0{,}46$	0,37	0,92	0,92
beds/spec.	0,22	0,10	9,82	0,07	$P\{0 < \hat{e}_{jk} < 0{,}5\} = 0{,}92$	0,00	0,97	0,04
beds/fac.	0,28	0,60	60,35	0,29	$P\{0 < \hat{e}_{jk} < 0{,}5\} = 0{,}34$	0,42	0,87	-0,17
beds/drugs	0,92	0,82	81,85	0,00	$P\{-0{,}5 < \hat{e}_{jk} < 0{,}0\} = 0{,}26$	0,53	0,85	-2,71
spec./fac.	-0,29	0,98	98,07	0,61	$P\{-0{,}5 < \hat{e}_{jk} < 0{,}0\} = 0{,}42$	0,61	0,86	-0,07
spec./drugs	-0,38	0,24	24,25	0,71	$P\{-0{,}5 < \hat{e}_{jk} < 0{,}0\} = 0{,}37$	0,66	0,88	0,17
fac./drugs	-0,21	0,19	18,72	0,22	$P\{0 < \hat{e}_{jk} < 0{,}5\} = 0{,}43$	0,47	0,96	-0,36

In the columns (4) to (7) we give some figures with respect to the simulated cumulative distributions.
Column (4) gives the probability that $\hat{e}_{jk} < e_{jk}$ (column 8) and column (5) the class with the most simulated $\hat{e}_{jk}$'s. We can conclude for several elasticities of substitution that there is a probability of 50% or more to be around the "true" e_{jk} (column 8). For the elasticity between staff and beds, 53% of the $\hat{e}_{jk}$'s is smaller than e_{jk} (0,31) and about 57% is between 0 and 0,5.
The probability that $\hat{e}_{jk}$ of beds and specialists is smaller than e_{jk} (0,04) is 0,07. This is very low. From column (5) we can draw the conclusion that more than 90% of the simulated $\hat{e}_{jk}$'s are between 0 and 0,5.
An exception is the elasticity of substitution between beds and drugs. In the analytical method this elasticity is also exceptional; it has the highest standard-deviation ($\hat{\sigma}_{\hat{e}_{jk}}$).

In the columns (6) and (7) the probability is given that the simulated $\hat{e}_{jk}$'s are smaller than 0 resp. 1, assuming the above mentioned translogmodel. The probability that $\hat{e}_{jk} < 1$ is very high.

To test whether our observations are in concordance with the more restrictive Cobb-Douglas model, we do a new simulation with the "true" elasticities of substitution equal to 1. Starting from the full translogmodel we make all b_{ij}'s equal to 0 and the a_i's equal to the actually obtained estimates of the outputelasticities α_i, corresponding to the average input-levels (table 18). We further assume the same covariance-matrix as in the first simulation. In table 55 we present the results of this simulation procedure.

Table 55. Results simulation procedure starting from Cobb-Douglas assumptions.

elasticity of subst.	$P\{\hat{e}_{jk}<1\}$	$P\{\hat{e}_{jk}<0\}$	$P\{\hat{e}_{jk}<e_{jk}\}$ (col. 8) (table 54)
staff/beds	0,75	0,24	0,39
staff/spec.	0,73	0,20	0,22
staff/fac.	0,63	0,14	0,12
staff/drugs	0,57	0,13	0,64
beds/spec.	0,54	0,19	0,23
beds/fac.	0,49	0,17	0,14
beds/drugs	0,67	0,12	0,00
spec./fac.	0,60	0,14	0,14
spec./drugs	0,68	0,14	0,18
fac./drugs	0,62	0,11	0,08

For all elasticities there is a probability between 50% and 70% that $\hat{e}_{jk} < 1$. The chances that $\hat{e}_{jk} < e_{jk}$ (the e_{jk}'s of col. 8, table 54) are lower than in the first simulation procedure, some of them considerably lower.
This indicates that the e_{jk}'s (col. 8, table 54) are not so probable under the Cobb-Douglas assumptions.

Recapitulating, we have indications that the substitution possibilities between the inputs with respect to the weighted admissions are smaller than 1.
This implies that for this aspect we reject the Cobb-Douglas specifications for some inputs. However, an accurate estimation of the elasticities of substitution, based on the available data, is difficult. This appears from both methods, described in this appendix.

The results of the simulation and analytical method, based on the translog models for the intermediary production and the weighted patient days are analogous to the results with respect to the weighted admissions.

Finally we remark that it seems that the simulated elasticities of substitution are not normally distributed and so we need more hospitals to satisfy the condition that e_{jk}'s are approximately normally distributed; the analytical method is only applicably as a very rough approximation in our case.

APPENDIX IV.8

Derivation of the effects of scale from translog production function.

The effects of scale are the change in the output from the same proportioned change in all the inputs. This implies that the effects of scale can be measured by the sum of the output elasticities.
Starting with a Cobb-Douglas production function the effects of scale are easy to calculate. With p inputs the Cobb-Douglas production function has the following form:

$$Q = A \cdot \prod_{i=1}^{p} X_i^{\alpha_i}$$

The output elasticity of input j is:

$$\frac{\partial Q}{\partial X_j} \cdot \frac{X_j}{Q} = A.\alpha_j.X_j^{\alpha_j -1} \cdot \prod_{\substack{i=1\\ i\neq j}}^{p} X_i^{\alpha_i} \cdot \frac{X_j}{Q} = A.\alpha_j \cdot \prod_{i=1}^{p} X_i^{\alpha_i} \cdot \frac{1}{Q} = \alpha_j$$

Then the effects of scale are: $\sum_{i=1}^{p} \alpha_i$; they are independent of the input levels.
The Cobb-Douglas production function is homogenous of degree one. The effects of scale are positive if:
$\sum_{i=1}^{p} \alpha_i > 1$ (economies of scale). In this case the output increases with more then 1% if all the inputs increase with 1%.

For the CES production function the degree of homogeneity is one of the estimated parameters.
For p inputs the translog production function has the following form:

$$\ln Q = a_o + \sum_{i=1}^{p} a_i.\ln X_i + \sum_{i\leq j}^{p} b_{ij}.\ln X_i.\ln X_j.$$

The output elasticity of input j is:

$$\alpha_j = \frac{\partial Q}{\partial X_j} \cdot \frac{X_j}{Q} = \frac{\partial \ln Q}{\partial \ln X_j} = a_j + 2\, b_{jj}.\ln X_j + \sum_{\substack{i=1\\ i\neq j}}^{p} b_{ij}.\ln X_i.$$

This gives a more complicated formula for the effects of scale ($\Sigma\alpha_j$). These effects of scale are dependent of the input levels. The function is not necessarily homogenous.
For statistical evaluation we need an estimate of the standard deviation. Therefore we define:

$$\hat{V} = \lceil \sigma_{a_1};\ \ldots;\ \sigma_{ap};\ 2\ln X_1\ \sigma_{b_{11}};\ \ldots;\ 2\ln X_p \cdot \sigma_{b_{pp}};$$

$$(\ln X_1 + \ln X_2)\ \sigma_{b_{12}};\ \ldots;\ (\ln X_{p-1} + \ln X_p)\ \sigma_{b_{p-1,p}} \rceil$$

Then the estimated variance of $\Sigma\alpha_j$ is:

$$\lceil\ \hat{V}\ \rceil \begin{bmatrix} \text{corr.} \\ \text{matrix} \\ \text{estimates} \end{bmatrix} \begin{bmatrix} \hat{V} \end{bmatrix}$$

APPENDIX IV.9

Output elasticities of the inputs at different input levels with respect to the intermediary production (5 inputs model).

In this appendix we calculate output elasticities of some inputs at different input levels based on the translog model of the weighted admissions with 5 inputs.

Table 56: Output elasticities of some inputs at varying levels of the number of beds, based on the translog production function of the intermediary production with 5 inputs.

function-group	input level: beds	staff $\hat{\mu}$	staff $\hat{\sigma}$	beds $\hat{\mu}$	beds $\hat{\sigma}$	drugs $\hat{\mu}$	drugs $\hat{\sigma}$
		output elasticities ($\hat{\mu}$) and standard deviation ($\hat{\sigma}$) of:					
I	125	-0,25	0,29	1,44	0,34	0,00	0,07
	150	0,01	0,18	1,09	0,19	0,05	0,04
	175	0,23	0,10	0,79	0,10	0,09	0,03
	200	0,42	0,10	0,54	0,11	0,12	0,03
	225	0,59	0,15	0,31	0,19	0,16	0,05
II	250	0,18	0,09	0,78	0,09	0,13	0,02
	275	0,32	0,08	0,60	0,08	0,15	0,03
	300	0,44	0,11	0,43	0,12	0,18	0,03
	325	0,56	0,15	0,28	0,18	0,20	0,04
III	350	0,11	0,09	0,81	0,09	0,11	0,03
	400	0,30	0,08	0,56	0,09	0,15	0,03
	450	0,47	0,14	0,33	0,17	0,18	0,04
	500	0,62	0,21	0,13	0,25	0,21	0,05
	550	0,75	0,27	-0,05	0,33	0,23	0,07
IV	600	0,10	0,12	0,73	0,12	0,17	0,04
	650	0,22	0,13	0,57	0,13	0,19	0,04
	700	0,32	0,16	0,43	0,17	0,21	0,05
	750	0,42	0,19	0,30	0,22	0,23	0,06
	800	0,51	0,23	0,18	0,27	0,25	0,06

APPENDIX IV.10

Output elasticities of the inputs at different input levels with respect to the intermediary production (7 inputs model).

In this appendix we calculate output elasticities of some inputs at different input levels based on the translog model of the intermediary production with 7 inputs.

Table 57: Output elasticities of some inputs at varying levels of the number of beds, based on the translog model of the intermediary production with 7 inputs.

function-group	input level: beds	registered nurses $\hat{\mu}$	registered nurses $\hat{\sigma}$	student nurses $\hat{\mu}$	student nurses $\hat{\sigma}$	paramed. staff $\hat{\mu}$	paramed. staff $\hat{\sigma}$
		output elasticities ($\hat{\mu}$) and standard deviation ($\hat{\sigma}$) of:					
I	125	-0,13	0,33	-0,13	0,23	0,27	0,16
	150	0,03	0,21	-0,06	0,16	0,20	0,11
	175	0,17	0,12	0,00	0,10	0,14	0,09
	200	0,29	0,11	0,06	0,08	0,10	0,08
	225	0,39	0,16	0,11	0,10	0,05	0,10
II	250	0,07	0,10	0,06	0,09	0,23	0,09
	275	0,15	0,07	0,10	0,07	0,20	0,08
	300	0,23	0,10	0,13	0,08	0,17	0,08
	325	0,30	0,15	0,17	0,10	0,14	0,09
III	350	0,00	0,12	0,13	0,09	0,28	0,11
	400	0,12	0,09	0,18	0,07	0,23	0,09
	450	0,22	0,14	0,23	0,10	0,19	0,10
	500	0,32	0,21	0,27	0,13	0,03	0,14
IV	550	0,00	0,16	0,09	0,11	0,33	0,13
	600	0,08	0,14	0,12	0,10	0,30	0,12
	650	0,15	0,15	0,16	0,10	0,27	0,12
	700	0,22	0,18	0,19	0,11	0,25	0,12
	750	0,28	0,22	0,21	0,13	0,22	0,13
	800	0,34	0,26	0,24	0,15	0,20	0,14

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Samenvatting

In dit proefschrift wordt een wetenschappelijke verantwoording gegeven van een gedeelte van het Basisonderzoek Kostenstructuur Ziekenhuizen (BKZ). Dit onderzoek wordt uitgevoerd onder verantwoordelijkheid van het Nationaal Ziekenhuisinstituut. In dit onderzoek wordt nagegaan of een econometrische benaderingswijze van nut kan zijn bij het verkrijgen van inzicht in de kosten- en productiestructuur van de algemene ziekenhuizen in Nederland. Aanleiding voor het onderzoek is meer inzicht te verkrijgen in de sterke kostenstijging in de ziekenhuissector. Welke factoren bepalen de kostenstijging? Hoe worden de productiefactoren benut?
In het eerste gedeelte van het onderzoek stond de analyse van de kostenstructuur van de algemene ziekenhuizen in 1971 centraal. Hieromtrent is gerapporteerd in een aantal rapporten. De centrale hypothese bij de opstelling van de kostenfuncties was dat factoren als de ziekenhuisfunctie, capaciteit, capaciteitsbenutting en overige ziekenhuiskenmerken belangrijke verklaringsgronden zijn voor de kostenverschillen tussen de ziekenhuizen. Dit bleek ook het geval te zijn.
Met behulp van de opgestelde kostenmodellen is men in staat een groot gedeelte van de kostenverschillen tussen de ziekenhuizen te verklaren. De parameterschattingen zijn in het algemeen in overeenstemming met de gestelde hypothesen.

Het onderwerp van onderhavig proefschrift is na te gaan of met behulp van productiefuncties meer inzicht kan worden verkregen in de productiestructuur en het funcioneren van de algemene ziekenhuizen. De studie heeft een methodologisch en exploratief karakter. Aan de hand van gegevens van een groot aantal ziekenhuizen in een bepaald jaar wordt nagegaan of en hoe de productiefunctietheorie op de ziekenhuissector kan worden toegepast.
De productiefunctie is een (technische) relatie tussen de output en de inputs.
Met behulp van productiefuncties is het mogelijk om meer inzicht te krijgen in de allocatie van de productiemiddelen.
De centrale hypothese is dat er sprake is van systematische relaties tussen enerzijds de verschillen in de output en anderzijds de verschillen in de inputs. Verondersteld wordt dat in de allocatie en de benutting van de inputs systematische elementen aanwezig zijn.
In deze studie wordt de output niet gedefinieerd in termen van de "outcome" van de zorgverlening maar noodzakelijkerwijze in termen van de productie. Onder inputs worden verstaan het aantal personeelsleden, de medische staf, het aantal bedden, de faciliteiten en de geneesmiddelen. Wanneer men in staat is de productiestructuur van ziekenhuizen te kwantificeren, wordt inzicht verkregen in een aantal economische karakteristieken, zoals de outputelasticiteiten, de substitutiemogelijkheden tussen de inputs en de schaaleffecten.
De betekenis hiervan ligt zowel in het vlak van de planning van ziekenhuisvoorzieningen als de exploitatiebeoordeling.

In het kader van de planning is meer inzicht in de mogelijke inputcombinaties gewenst. De productiefunctie geeft aan welke alternatieve inputcombinaties in de praktijk gerealiseerd zijn.
In het kader van de exploitatiebeoordeling geeft de productiefunctie inzicht in de benutting van de inputs.
Gezien de relatie tussen de kosten- en productiefunctie is in dit proefschrift, evenals in dat van Van Aert, uitgegaan van het jaar 1971. Overigens ligt het in de bedoeling zowel de kosten- als de productiefunctie over een reeks van meer recente jaren te analyseren. Dit kan worden uitgevoerd als de actualisering van het gegevensbestand dat in het kader van het BKZ is opgebouwd, is afgerond.

In hoofdstuk I wordt een uitgebreide inleiding en samenvatting gegeven van het onderzoek. Dit hoofdstuk is te lezen zonder uitgebreide kennis van econometrische methoden en technieken. Begonnen wordt met een beschrijving van de probleemstelling, de hypothesen en de productiestructuur in de nederlandse ziekenhuissector. Vervolgens wordt voor minder ingewijden in het kort de productiefunctietheorie beschreven, waarbij vooral wordt ingegaan op die aspecten die relevant zijn voor ons onderzoek. Specifiek wordt aandacht gegeven aan de relaties tussen de productie- en de kostenfuncties.
Nadat verschillende definities van de output (gewogen opnamen, gewogen verpleegdagen, intermediaire productie) en de inputs (personeel, bedden, specialisten, faciliteitenindex, geneesmiddelen) van een ziekenhuis zijn behandeld, worden mede op basis van de beschrijving van het allocatieproces enkele alternatieve modelspecificaties geformuleerd en getoetst.
Vervolgens worden de resultaten geïnterpreteerd in termen van de outputelasticiteiten, de schaaleffecten en de substitutie-elasticiteiten. De geschatte ("gemiddelde") productiefunctie biedt de mogelijkheid de posities van de (algemene) ziekenhuizen met betrekking tot de benutting van de inputs ten opzichte van elkaar aan te geven. Relatering hiervan aan een groot aantal variabelen geven indicaties omtrent het instrument karakter -althans in zekere mate- van de gemiddelde verpleegduur.
Naast een "gemiddelde" productiefunctie is op basis van de ziekenhuizen welke een relatief "betere positie" hebben, een "meer efficiëntere" productiefunctie geschat.
Tenslotte worden enkele implementatiemogelijkheden van de productie- en kostenfuncties aangegeven in het kader van de externe bedrijfsvergelijking.
In hoofdstuk II worden een aantal productiefunctiespecificaties behandeld en wordt een beschouwing gegeven van enkele buitenlandse toepassingen van de productiefunctietheorie op de ziekenhuissector in het kader van de externe bedrijfsvergelijking. Geconcludeerd kan worden dat de productiefunctietheorie op verschillende wijzen wordt toegepast en dat samenhangend hiermee ook verschillende resultaten worden verkregen. In hoofdstuk IV worden deze vergeleken met de bevindingen van onderhavige studie. In hoofdstuk III wordt uitgebreid ingegaan op het theoretische kader voor de toepassing van de productiefunctietheorie op de Nederlandse ziekenhuizen.

De output en de inputs worden gedefinieerd en de allocatie-procedure wordt beschreven. Vervolgens worden in hoofdstuk IV een aantal verschillende productiefunctiespecificaties geschat.
In hoofdstuk V wordt aandacht geschonken aan vergelijkingsmaatstaven (indices) voor het gedrag van ziekenhuizen.
Deze indices zijn gebaseerd op de geschatte kosten- en productiefuncties en kunnen een bijdrage leveren voor een meer genuanceerde externe bedrijfsvergelijking.
Geconcludeerd wordt dat de productiefunctietheorie goede mogelijkheden biedt om meer inzicht te krijgen in de productiestructuur van de algemene ziekenhuizen.